Managing Woodlands in a Changing Climate

Nova Scotia Department of Natural Resources and Renewables

Module 19

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Managing Woodlands in a Changing Climate.

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Cole Vail*, James Steenberg, Peter Duinker, & Jane Barker
Herring Cove, NS
colevail423@gmail.com

*Corresponding Author

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All photos belong to MTRI, unless otherwise noted.

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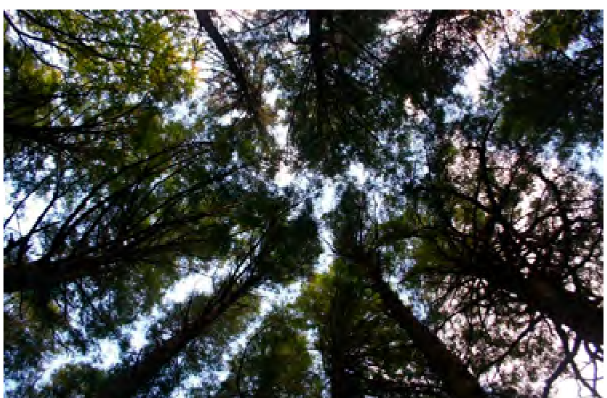
Introduction

Introduction

In recent years, it has become harder and harder to ignore the fact that our climate is changing. Across the world, humans are witnessing the effects of a shifting climate, such as the melting of sea ice, rising sea levels, prolonged drought conditions, and more frequent and intense storms. Global news reports reflect the negative impacts of these changes on a daily basis, but the influence of a changing climate can also be observed locally, in your own backyard! The way you manage your woodland can a have an impact on how vulnerable it may be to extreme weather events. The very act of managing a forest influences climate change – albeit on a micro scale, but collectively, our forests can make a real difference. Woodland management can also benefit carbon storage, erosion control, and general forest health, increasing resistance to pests and diseases. Climate change is a complex subject, but by better understanding our weather patterns, and what is driving shifts in climate, we can predict what to expect more accurately, and manage forests so that they will be more able to withstand the impacts of these inevitable changes in the future.

Weather



An old-growth forest canopy (photo credit: Peter Duinker)

Weather describes a single event or short timespan, with no one form of weather being the same as another. We can use the encompassing term to describe many meteorological events such as rain, snow, heatwaves, or high winds. Weather is described in terms of hours, a day, or a week. It could be detailed in the amount of rain or snow that is expected to occur or did occur in a single day. It may describe the weather that has occurred throughout the length of a season, comparing what we had during June to what we experienced in August.

However, as soon as one starts to track how many hot days occurred in June as compared to August and think about ranges and averages of temperatures, or how the Annapolis Valley received less rain on average than Halifax, we are starting to talk about climate.

Climate

Climate refers to the general trends of weather locally, within a region, or globally. Climate is not measured in singular events but rather in long-term patterns, such as average yearly precipitation or temperature. These are not the only things measured by climatologists. Numerous other measurements are required, such as wind velocity and sunshine – often termed as 'solar radiation' – or the number of hurricanes expected in a season. The main difference between weather and climate lies in what is measured and for how long. Climate refers to weather trends and is measured across seasons or years to decades.

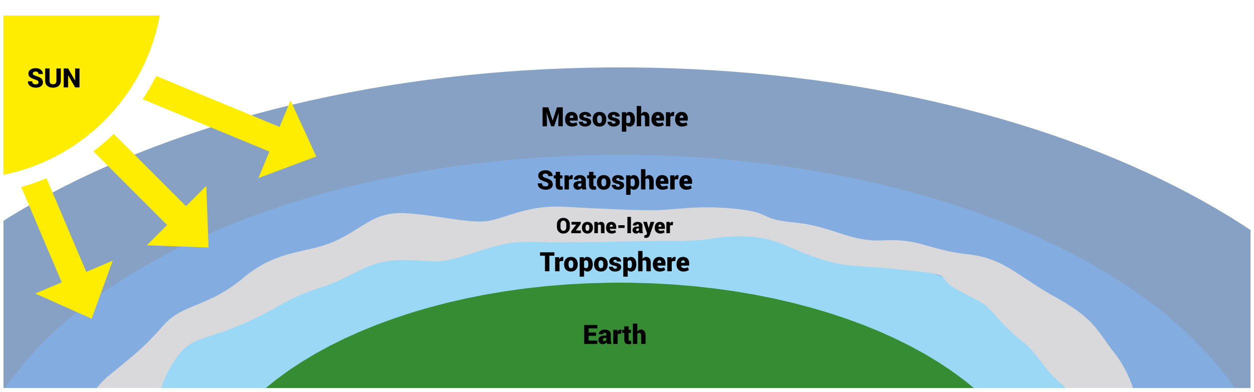
What Drives Climate?

Before we can really understand climate change itself, we will need to understand what factors influence climate. Many things affect regional climate, like mountain ranges or vast forests or huge bodies of water like the Atlantic Ocean. About 70% of the Earth's surface is covered in water[1].

Therefore only 30% is made up of land masses, i.e. the continents. A third of that land is covered in forest, with most of that forest lying in the temperate and tropical regions of our planet[2]. These landmasses all have different formations and compositions which contribute to the climates we expect and experience. For example, take the North and South Mountains of the Annapolis Valley; these two ridges shelter the Annapolis Valley from the winds of both the Bay of Fundy to the north and the larger Atlantic Ocean to the south. This shelter contributes to a warmer climate and allows for the growth of crops like wine grapes and peaches.

The main influencer of climate, however, is **solar radiation**. This source of energy drives how our winds move, the average temperature of a given month, and the amount of precipitation we can expect over a season[3].

The sun's radiant energy is always hitting the Earth at some point and transfers the most energy to tropical and subtropical portions of

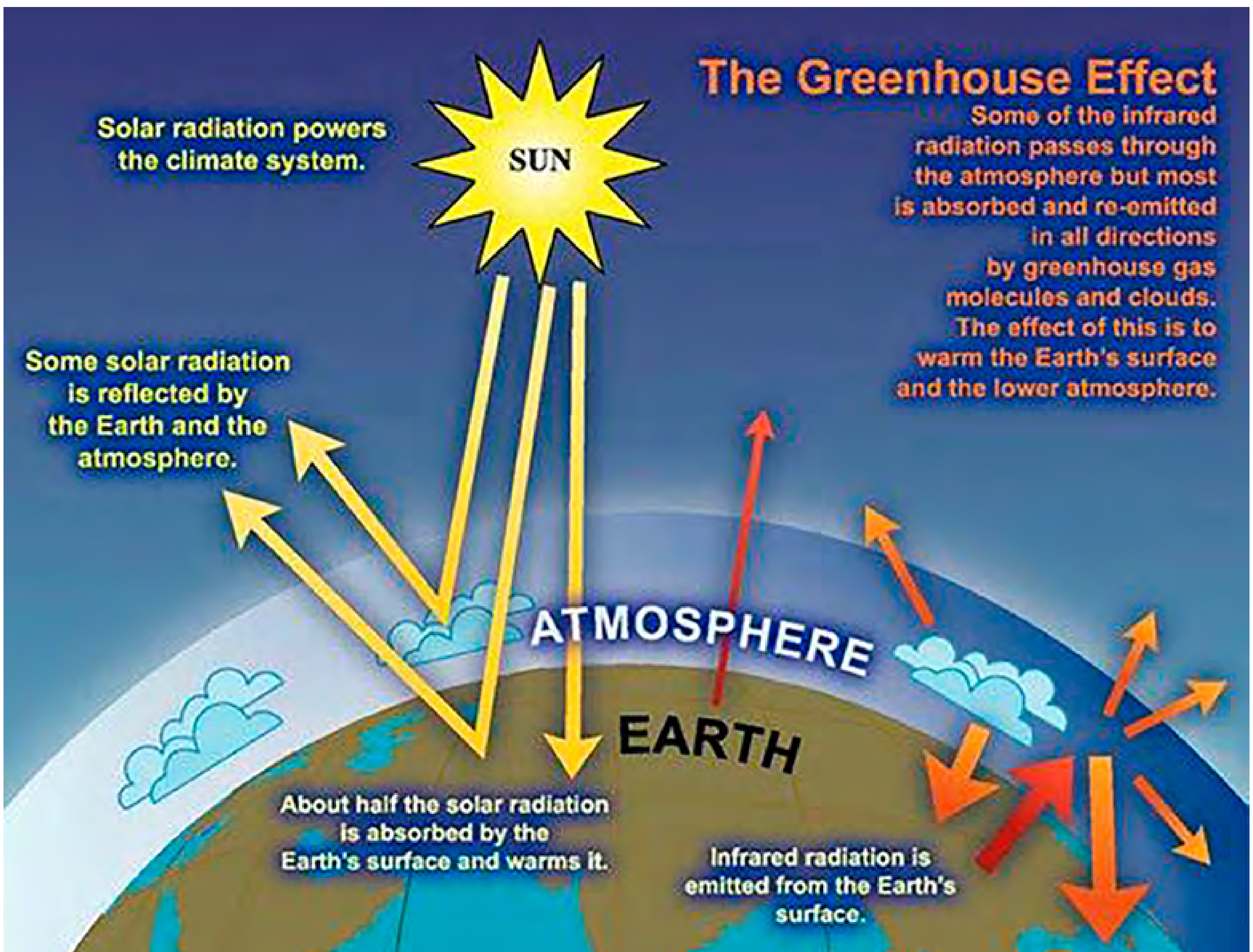


our planet. Some of this energy is reflected into the **atmosphere**. The atmosphere is made up of a mixture of gases.

The layer we live in where weather occurs, the **troposphere**, extends from earth's surface up to the **stratosphere**. There is a small intermediary layer between the troposphere and stratosphere called the **ozone layer**. This ozone layer essentially acts as a protective layer against the sun's most harmful radiation (UV rays)[4].

When solar radiation enters our atmosphere, some of it is reflected back into space by the atmosphere. Also within the atmosphere are **greenhouse gases**. The main gases are carbon dioxide (CO_2), water vapour, methane, chlorofluorocarbons, and nitrous oxide[5]. The solar radiation that makes it through the atmosphere is absorbed by the surface of the Earth and then emitted back as **infrared radiation**. Greenhouse gases trap some of that energy being emitted and keep it in the atmosphere, causing it to warm. This process is termed the **greenhouse effect** and it is responsible for maintaining temperatures on the Earth for life as we know it.

Earth regularly reflects about 31% of the sun's solar radiation back to space[6]. The global climate would remain relatively constant if this reflection rate remained



A diagram of the greenhouse effect (figure source: Intergovernmental Panel on Climate Change).

constant. Massive changes to this process would cause an imbalance in the earth-sun energy exchange, causing a warming or cooling of the global temperature.

Normally, this energy absorption is a necessary part of everyday life on the planet. However, by adding gases like carbon dioxide and other greenhouse gases through pollution, humans are increasing the greenhouse effect. When we add more and more greenhouse gases in a relatively short period of time – say, since the industrial revolution – the energy balance of Earth's atmosphere and the normal climate and weather it creates is altered. This is climate change.

The winds of the world themselves are powered through solar radiation. Some regions of the world get more radiation than others. Air around the Equator is heated much more than in polar regions. This mismatch in energy drives major air currents and winds across the globe. Oceans serve to chill or warm those winds that travel over them, depending on the temperature and salinity of surface waters.

Moisture from evaporation can accumulate in the atmosphere and mingle with particles and dust to create clouds that travel on the world's winds. These drop precipitation and serve to cool landscapes as they travel overhead[7]. **Precipitation** is the term we use for liquid or frozen water, like rain, sleet or snow, that forms in the atmosphere and falls to the Earth. Our global ecosystem is a complex system, with multiple parts all playing roles in producing the environmental conditions of the world.

Climate Change: The Main Culprits

Climate change is commonly used interchangeably with the term **global warming**. However, climate change is more accurate because warming temperatures are just one of many impacts. Climate change refers to *both natural and human-driven* warming and its *effects* on the planet, though the current bout of climate change results mainly from human-caused greenhouse gas emissions and global deforestation. Global warming is an umbrella term for the *human-driven* warming of the earth's surface[8].

A melting glacier (photo source: Microsoft repository)

The Earth's surface temperature has increased by roughly 1°C since the pre-industrial era and is now increasing by 0.32°C per decade. The ten warmest years on record have occurred since 2005[9]. While the optimistic target for the global rise in temperature is 1.5°C above the baseline, the global temperature could rise anywhere from 1.1°C to 5.4°C by 2100 based on our actions[10]. Global warming is generally blamed on our production and emission of greenhouse gases. The lion's share of those emissions come from burning fossil fuels. However, the Earth's forests are huge reservoirs of carbon (this will be discussed in detail in Lesson 5), and deforestation caused by land-clearing for agriculture and development also contribute to climate change.

The main reason for linking climate change to the end of the pre-industrial era is due to the overall rapid increase of CO_2 and other gases in the Earth's atmosphere since that period. This rapid increase largely correlates with increased industrial and manufacturing activity and especially widespread and early use of coal, one of the highest CO_2-emitting sources of energy. Despite being a major source of energy in the past, coal is now considered the most environmentally harmful energy source. Coal mining alone emits gases like CO_2, methane, sulfate, nitrous oxides, and carbon monoxide[11]. Energy production is the biggest source of greenhouse gas emissions, though of course industrial activity, transportation, and buildings (e.g., heating and cooling) also play large roles.

In 1975, petroleum combustion surpassed coal combustion as a source of CO_2 emissions. Another fossil-fuel energy source is natural gas, which is composed mostly of methane. Natural gas burns more cleanly than coal or petroleum. It is in limited supply compared to petroleum or coal, but its use for energy production has become prominent since the twentieth century.

As a result of their digestion process, cows are a major source of methane emissions (photo source: Microsoft repository)

Another source of greenhouse gases is agriculture. In addition to land conversion and the burning of grasses and other agricultural by-products, the production of meat – specifically beef – accounts for a quarter of the annual emissions of methane. Due to several factors, including agriculture, the concentration of methane in the atmosphere has more than doubled in the last 200 years[12]. Agricultural soil management and fertilizer usage is also a major contributor of nitrous oxide[13]. While methane and nitrous oxide are less abundant in the atmosphere, they are much stronger greenhouse gases than CO_2.

What Does Climate Change Look Like?

Global Implications

As previously discussed, solar radiation plays an essential part in how our global climate works, and greenhouse gases trap infrared radiation in our atmosphere and increase warming.

Despite the average Earth's surface

temperature increasing, not every region will become warmer. Some parts of the planet could be expected to cool[14]. Climate change could result in a variety of seasonal changes across different regions of the globe. One major general trend includes rising sea levels due to **thermal expansion** of ocean water as well as melting snow and glaciers in the polar regions[15]. In addition to this, Nova Scotia can expect more intense hurricanes of increased strength[16]. Warmer waters and increased atmospheric moisture fuel these powerful storms.

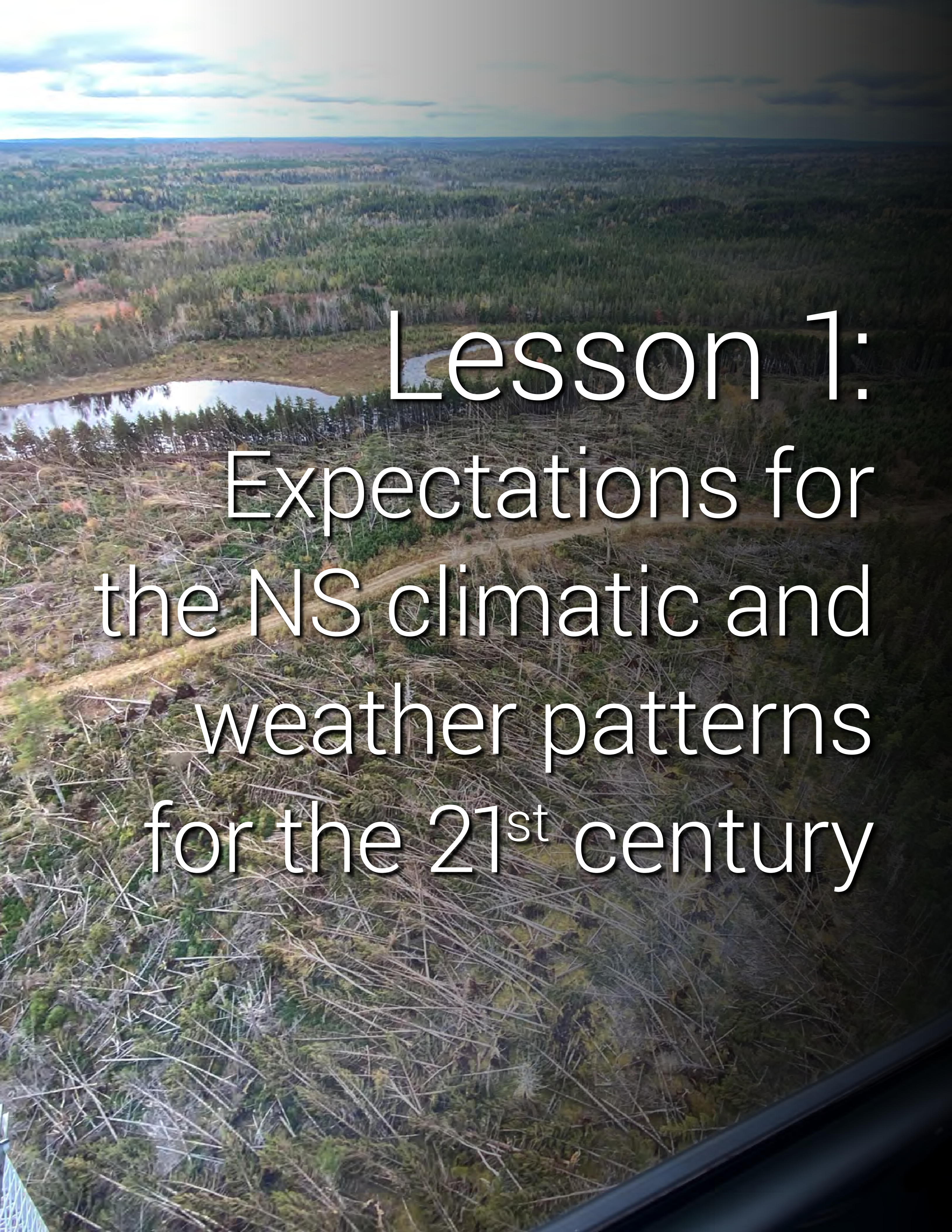
Drought conditions will likely become more common globally in future climate (photo source: Microsoft repository).

Another expected effect of climate change is more extreme temperatures and environmental conditions that result. Think of **drought**, for a moment. A drought can be defined as a lack of precipitation for extended periods of time, resulting in a shortage of water. Increased air temperatures due to the greenhouse effect will increase evaporation rates, reducing the amount of surface water or reserves within plants, including trees. The Southwestern United States has already experienced a decrease in annual precipitation since the beginning of the twentieth century and 81% of the United States experienced abnormally dry conditions at the peak of the 2012 drought period[17]. Western Canada has been experiencing abnormal drought and extreme heat conditions recently, leading to extensive wildfires. These are just a few examples of how climate change occurs on a generalized global scale.

Regional Expectations

Average temperatures have increased by 1.3°C across Canada over the last century, while Atlantic Canada has seen an overall temperature increase of 0.3°C[18]. Due to the varied composition of Atlantic Canada's geography, and the range of ecosystems and climate types within it, it is difficult to give exact numbers for the entire region. For instance, precipitation has increased by approximately 10% across the region, but the percent increase for different areas within the larger Atlantic region vary greatly[19], as does the timing and seasonality of that rainfall. As a result, the expected changes in temperature and precipitation are given in ranges to reflect these variations.

By 2050, summer temperatures may see an increase of 2-4°C, while winter temperatures may see an increase of 1.5-6°C. Overall, the mean annual minimum and maximum air temperatures are expected to increase by 5°C and 4°C respectively[20]. Overall, we can expect that the Atlantic region will become warmer. The average annual precipitation is also expected to rise, though northern Nova Scotia and eastern New Brunswick are expected to see a small decrease[21]. All said and done, the Atlantic region – with a few exceptions – will become wetter. Coastal areas in Atlantic Canada can expect to see a 60 cm increase in sea levels, which will lead to increased flooding in some coastal areas. Coastal flooding will be an issue, but more rainfall and more intense storms are also causing overland flooding to be on the rise.



Lesson 1: Expectations for the NS climatic and weather patterns for the 21st century

With an understanding the basics of climate, we can start to appreciate what variations we would have normally expected in the past. In this lesson, we'll look at how we decide what is normal, and what change will look like. How will the daily local weather of Nova Scotia change, and how can we predict what will happen in the future? In addition, we will look at tools such as climate models being developed to help guide our expectations for the future.

What is normal for Nova Scotia?

"If you don't like the weather, wait five minutes!" is a common saying in Nova Scotia, expressing the seemingly ever-changing weather patterns. But what does normal weather look like here? **Climate normals** refer to a set of calculations based on observed climate variables in a particular place over a specific period of time. The main climate variables are air temperature, precipitation, evaporation, and soil temperature. The standard period, as decided by the World Meteorological Organization (WMO), is 30 years of uninterrupted measurements[22].

There are 47 weather monitoring stations in Nova Scotia, but only four of those meet the WMO standards: Yarmouth, Greenwood, Halifax, and Sydney. These stations provide researchers with a wide representation of Nova Scotia's climate, examining average daily temperatures and precipitation amounts, maximum and minimum extreme temperatures, and a host of other variables. Other stations in Nova Scotia that do not meet the WMO standards are known as volunteer stations. These stations may only record temperature and precipitation values and may not record values like wind velocity or soil temperature. All of the data in this lesson were taken from the 1981-2010 Climate Normals and Station Results Data Set, found **here**[23] or at the end of the learning module in the references.

Another good resource for profiling the differences in climate across Nova Scotia's landscapes is the Ecological Land Classification guide developed by the Department of Natural Resources and Renewables. It is available in print by order and online **here**.

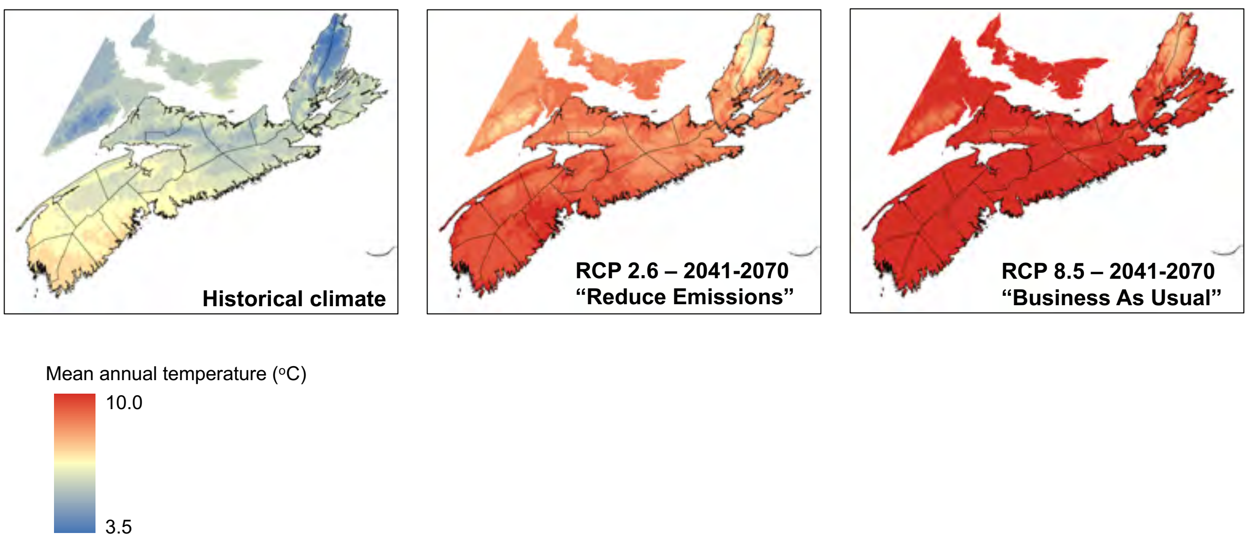
Example of weather station used by Environment and Climate Change Canada (photo credit: Environment and Climate Change Canada).

Temperature Patterns

The two hottest months in Nova Scotia are generally July and August, while the two coldest months are January and February. However, the range of temperatures as well as precipitation can vary greatly across the province.

Some common terms used in describing temperature patterns are **daily minimum**, **daily maximum**, **extreme maximum**, and **extreme minimum**. For example, the daily minimums and maximums for May would take all the daily minimums and maximums within the month of May over many years and average them. The extreme minimum and maximums simply tell us the hottest or coldest temperature extremes that a month may have had.

Greenwood (in the Annapolis Valley) is by far the hottest area among the weather stations in Nova Scotia. While it may have experienced average temperatures only about ~2°C above the other regions, the higher average number of days with temperatures above a certain threshold give a better understanding of the localised climate.



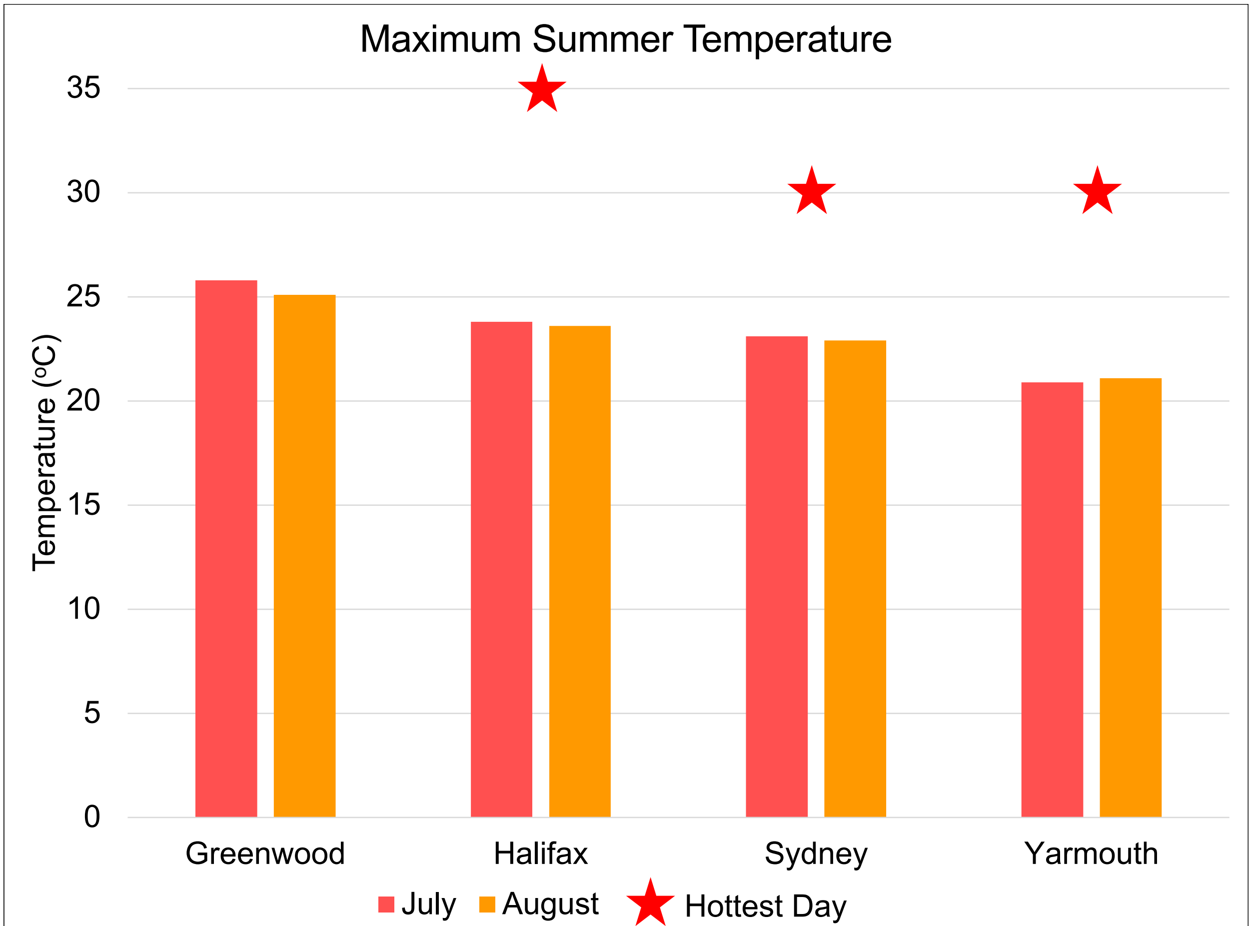
Mapped climate predictions for Nova Scotia (data credit: Natural Resources Canada, figure credit: James Steenberg). Refer to the next section for an explanation of Representative Concentration Pathways (RCPs).

Take the average number of days in each year with temperatures above 20°C in Yarmouth and Greenwood, for example. Yarmouth experienced 57, while Greenwood experienced twice as many (110 days). Greenwood experienced more and significantly hotter days on average each year across 1981-2010 than any other region in the province. While not in the 1981-2010 period, Greenwood has previously registered the hottest day among the four regions in August 1944, where it reached 37.2°C. The hottest day on record in all of Nova Scotia was in Ashdale (previously Collegeville), Antigonish County, getting to 38.3°C on August 19, 1935.

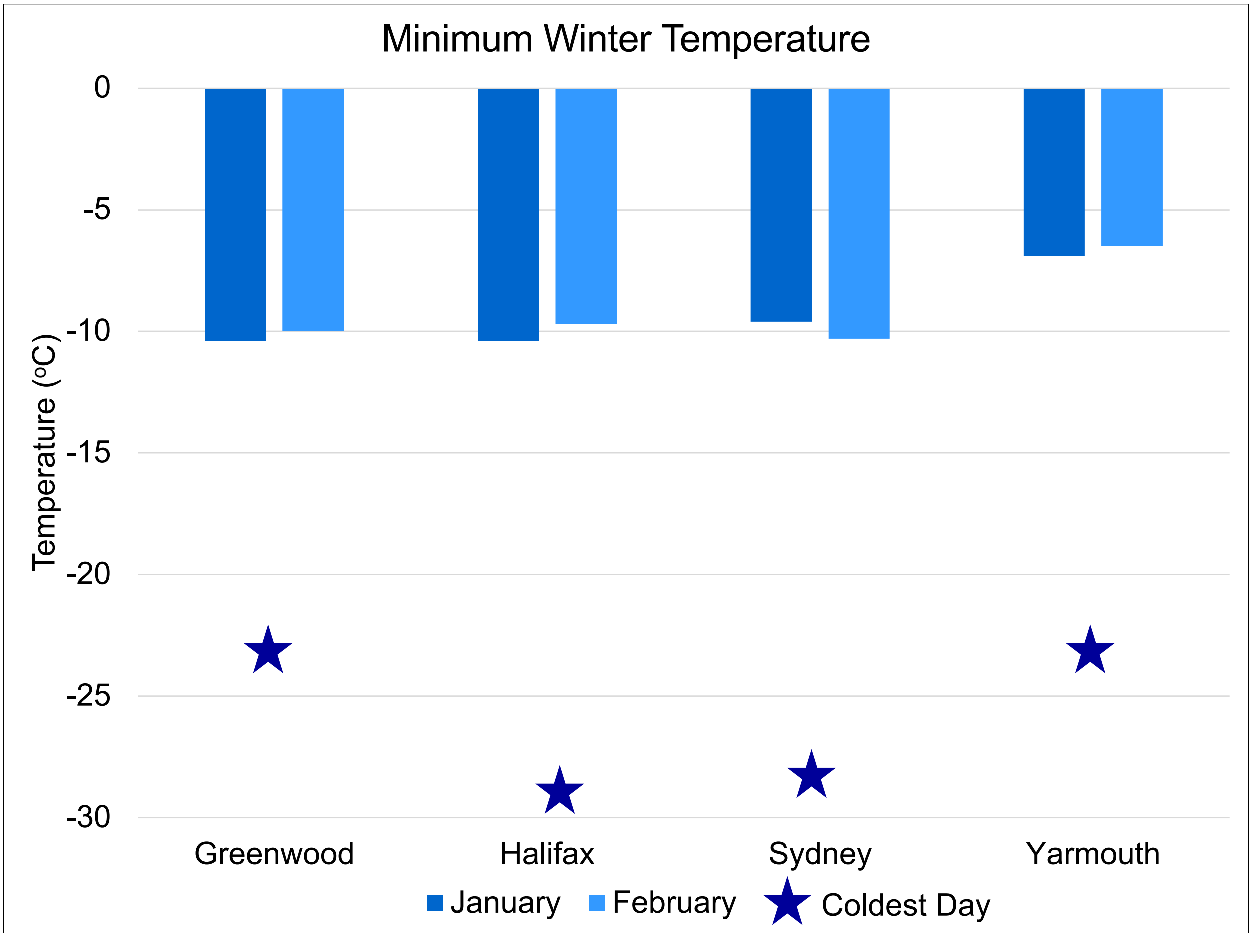
Greenwood conversely also experienced the coldest winters on average, holding the record for coldest day in the 1981-2010

Nova Scotian climate, getting as far down as -35.5°C on February 7 of 1993. While only slightly, Greenwood experienced more days below -20°C and -30°C than the other principal stations of Nova Scotia.

Overall, summers in Nova Scotia are moderately hot, with some regions hotter than others. Every region at least occasionally experienced temperature above 30°C throughout 1981-2010. Winters in Nova Scotia are usually mild in nature, with temperature rarely dropping below -20°C on average through a year's time, though some regions are an exception.



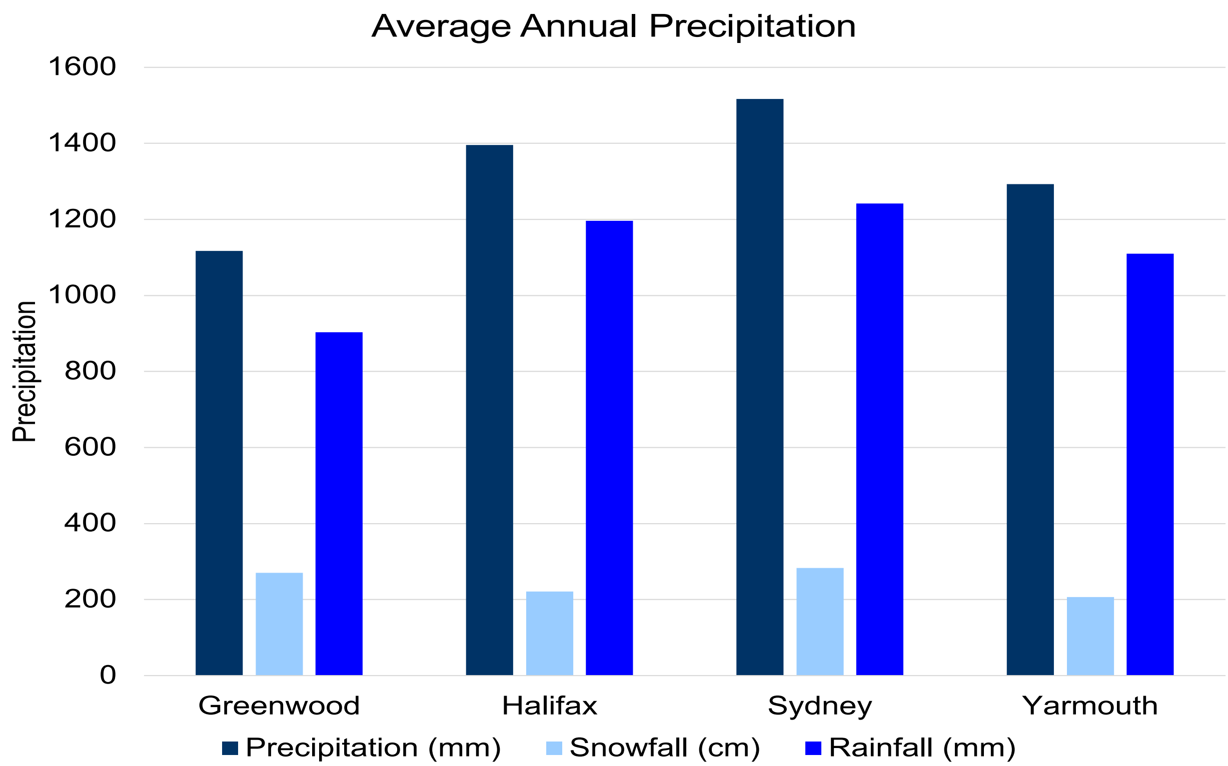
Maximum summer temperatures and hottest days in four regions of Nova Scotia. Data represent the average maximum temperature of these months between 1981 and 2010. Note that there is no hottest day record for Greenwood.



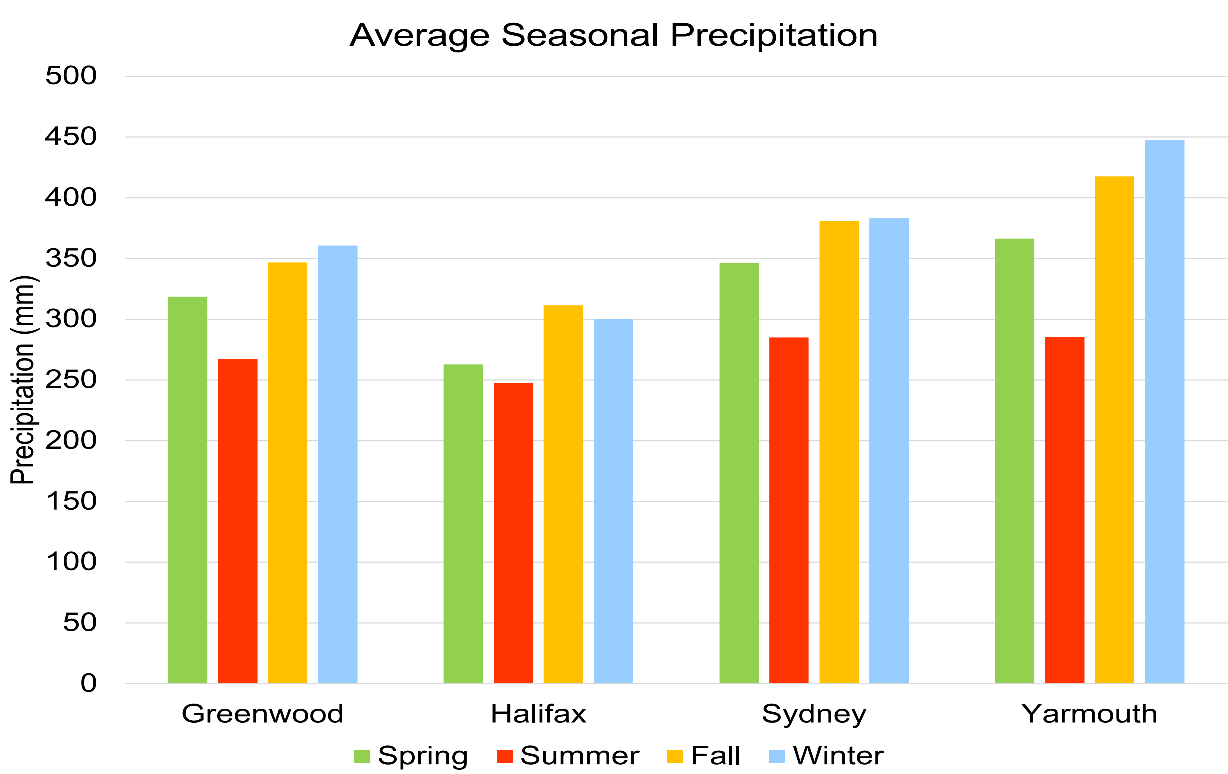
Minimum winter temperatures and coldest days in four regions of Nova Scotia. The data represent the average minimum temperature of these months between 1981 and 2010.

Precipitation Patterns

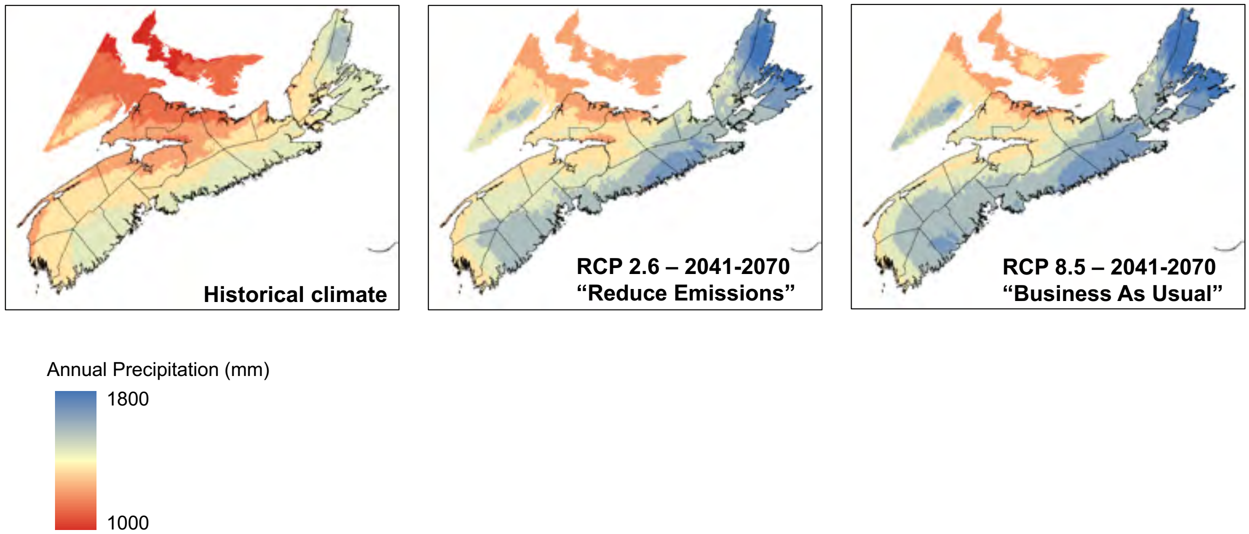
Precipitation is a broad term that includes snowfall, rainfall, hail, and sleet. Rainfall amounts can vary across regions, though all the regions follow a general trend of higher levels of rainfall during the late fall through winter. When we refer to rainfall here, it is the average rainfall amounts for every month during the period of 1981-2010. This lesson has compounded the months based on season. An average yearly amount is also given. The snowfall amount is calculated the same way, while the extreme daily amounts of both simply tell us the highest amount of rain or snowfall a particular region has received in one day. Readers should note that snowfall amounts are given in cm, so when reading about precipitation, rainfall, and snowfall amounts, take care to realize that 10 mm of rain (or 1.0 cm) very roughly is equivalent to about 10 cm of freshly fallen snow.



Average annual precipitation, snowfall, and rainfall in four regions of Nova Scotia between 1981 and 2010. Note that precipitation includes all snowfall and rainfall combined and that snowfall is shown in centimetres in the graph while precipitation and rainfall are in millimetres.



Average seasonal precipitation in four regions of Nova Scotia between 1981 and 2010.



Mapped climate predictions for Nova Scotia (data credit: Natural Resources Canada, figure credit: James Steenberg). Refer to the next section for an explanation of Representative Concentration Pathways (RCPs).

As we could see in the numbers for each region, it appears that there is a longer, wetter season that extends from fall until spring and a short drier period during summer. September appears to represent a bit of a transitionary period between the dry summer and mild and wet winters the province seems to experience more broadly. Springtime in Nova Scotia is relatively wet in terms of total precipitation amounts. Halifax and Sydney also experience significantly more precipitation during the spring and late fall than Yarmouth and significantly more than Greenwood, with Sydney receiving more rainfall in a year (1517 mm) than any other region. Greenwood receives the least amount of precipitation in a year, at 1117 mm.

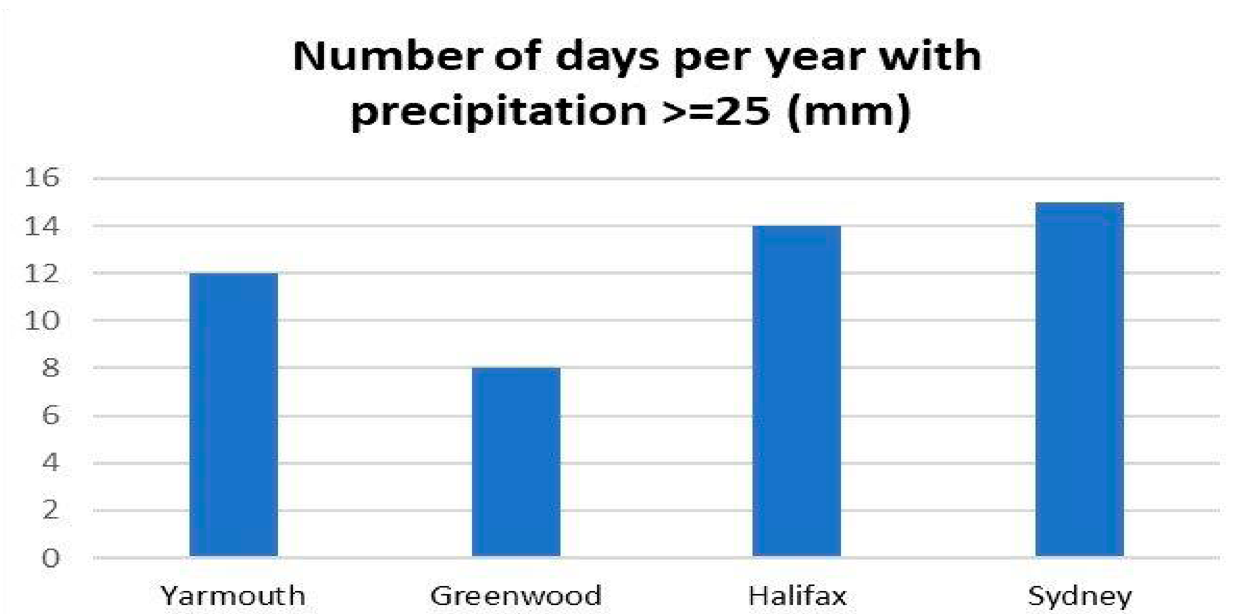


Figure 7: The average amount of days a year exceeding 25 mm of precipitation between 1981 and 2010

In addition to total precipitation, the frequency of extreme precipitation events also differs across regions. Greenwood, in addition to experiencing the least amount of precipitation annually, also receives that precipitation in smaller events than other regions.

Nova Scotia's precipitation is well distributed through the year, with total amounts varying greatly across the province (photo source: Microsoft repository).

Wind

Being a maritime province surrounded by ocean, Nova Scotia is a windy place, especially along its coasts. Yarmouth and Sydney have higher average windspeeds throughout the year, both experiencing 17.5 km/h winds year-round. Halifax has a slightly lower yearly average at 16.5 km/h, while Greenwood has calmer winds at 14.2 km/h over the year. Over the entirety of the province, peak winds occur in the winter months, specifically January, with a leveling out in July and August. Yarmouth and Sydney, for example, experience daily average wind speeds of 20.7 km/h and 19.8 km/h. This is not indicative of how often extreme winds occur, however. Greenwood, while experiencing lower daily average wind-speeds, also experiences significantly more days with wind-speeds above 52 km/h – or even 63 km/h – than other regions of Nova Scotia. Greenwood also experienced higher maximum wind gusts than other regions of the province.

Nova Scotia rests in the North Atlantic, and in addition to cold Nor'easters coming down from the North, it also experiences severe storms, like hurricanes, from the south. Since records began in 1871, 34 named storms have hit Nova Scotia's shores. At the time of writing, thirteen of these have been hurricanes, with an average of about one storm every four years. Strong storms have been shown to have increased in intensity since the 1970s.

Damage sustained during Hurricane Juan in Oakfield Provincial Park (photo credit: NSDNRR).

What does the future hold?

What are we aiming for?

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and published its first report in 1990. In each of these reports, the IPCC covers all the potential risks of climate change as well as recommendations for policymakers and governments not only to lower greenhouse gas emissions but to reduce future impacts of climate change[24]. These documents, along with other data provided by individual countries, are used during the **Conference of the Parties** (CoP) to review progress and ensure that industrialized and pre-industrialized countries keep on track with the United Nations' mandates.

General Circulation Models

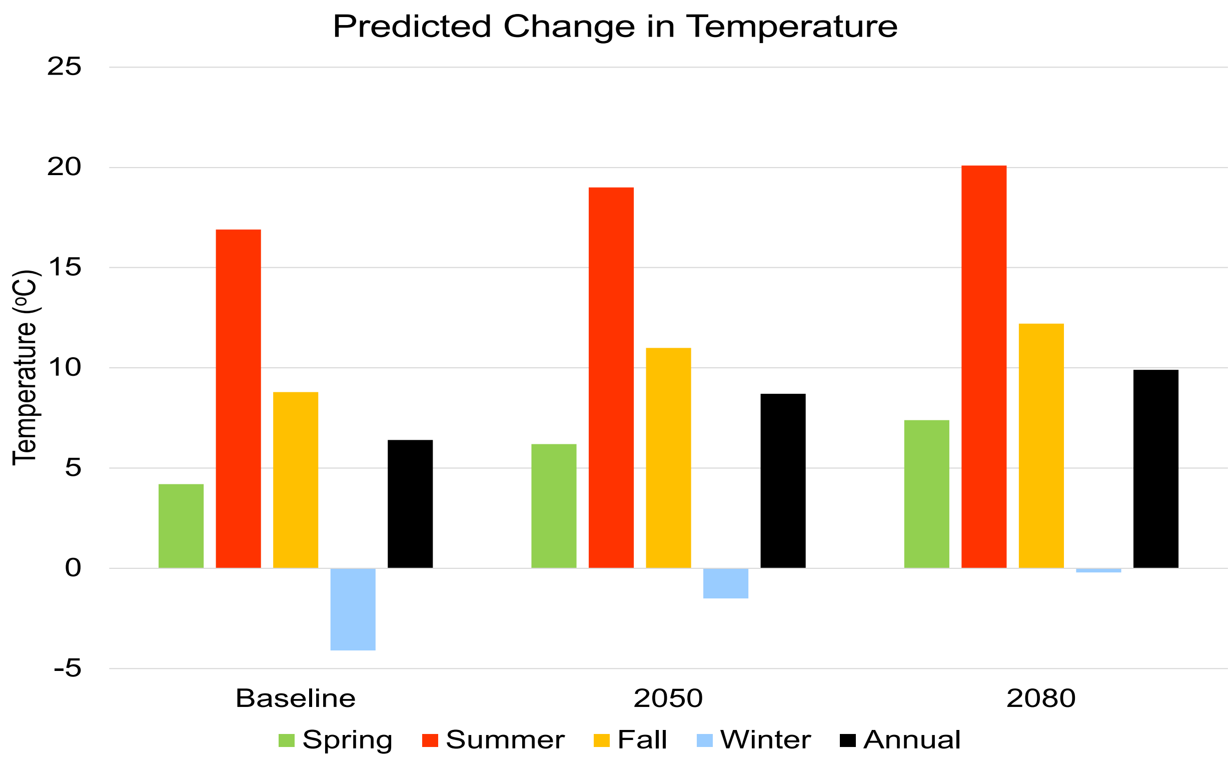
The IPCC"s participating scientific labs use **General Circulation Models** (GCMs) to predict the possible changes that may occur in our near and distant future. These GCMs are complex computer models that predict the Earth's climate and come in various forms. They can vary in complexity from simple GCMs that consider only the atmosphere, to models that link together the atmosphere and the oceans[25].

When a GCM is used, it simulates what different levels of greenhouse gas emissions will do to the Earth's climate. Due to the uncertainty of predicting our climate future and our future levels of emissions, scientists develop several different scenarios when using GCMs. These scenarios, today known as **representative concentration pathways** (RCPs), describe the long-term trend of greenhouse gas emissions and land-cover change up to the year 2100[26, 27]. The most severe climate change occurs in the scenario where emissions level remains steady, or "business-as-usual" (called RCP 8.5) while the highest curbing of emissions happens in a 'reduce emissions scenario" (called RCP 2.6).

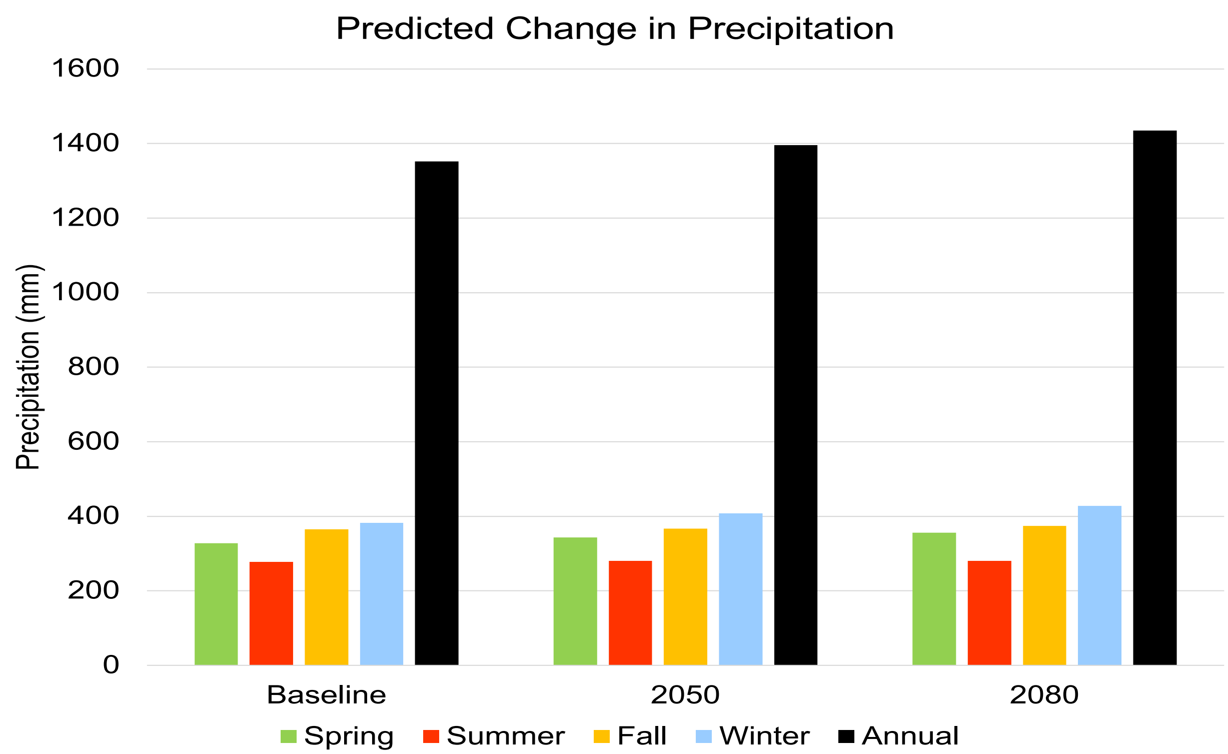
What changes are happening now, and what can we expect in the future?

Since 1895 up to 1998, average temperatures in Nova Scotia have increased by 0.5°C and are likely to increase another degree or more by the 2020s[28]. Due to the variability between regions, a change in precipitation trends has been historically difficult to generalize. However, many parts of Nova Scotia have experienced an increased amount of precipitation, though snow cover and snowfall have decreased.

Overall, we can expect to see a general increase of 3-4°C from the historical baseline of the 1980s. We can likely expect extremely hot days exceeding 35°C to become more common. Very hot days, with maximum temperatures of at least 30°C, are expected to rise from two days a year to ten days a year on average. Extremely hot days will become even more common[29].



Projections of annual and seasonal temperatures across the province of Nova Scotia for both 2050 and 2080, along with the baseline climate (1981 to 2010).



Projections of annual and seasonal precipitation across the province of Nova Scotia for both 2050 and 2080, along with the baseline climate (1981 to 2010).

Although one can expect more precipitation overall, it is expected that the precipitation type will also change drastically. Increasing temperatures during the winter months will result in increased rainfall rather than snowfall during winter. Instead of heavy snow, Nova Scotia could expect to get light snowfall during lower temperatures, transitioning to rain when temperatures increase during the day[30].

Increasing temperatures will mean less days with frost and a longer growing season (photo credit: Microsoft repository).

With more-frequent, intense rainfall occurrences rising from a baseline 0% to 9% in 2050 and 16% in 2080, Nova Scotia will likely see more downpours interspersed with dry spells in the spring and summer and intense precipitation in the winter months.

A change in temperature regimes will have drastic effects on growing seasons, affecting forestry as well as agriculture. Our frost-free period is expected to rise from a baseline of around 200 days a year to 240 days a year in 2050, continuing to 259 days a year in 2080. The growing season will also increase from 180 days in the 1980s to 209 days in 2050 and 226 days in 2080[31]. In addition to changing temperature and precipitation regimes, severe storms like hurricanes will also increase in intensity and frequency. Winter storms (Nor'easters) and summer thunderstorms are also on the rise, fueled by climate change. These weather events affect people and forests alike and we will learn more about them in Lessons 2 and 3.

"The only certain thing is uncertainty"

The most important thing to consider when it comes to climate change and woodlands is **uncertainty**. We can say with certainty that things will change, and the climate will not be the same in 2050 or 2100 as we see it today, but we cannot say with confidence by how much. While there is still time to make changes that can help reduce the impacts of climate change such as reducing greenhouse gas emissions and managing forests carefully, we do not know the ongoing severity of what we will face or what that means for forests. Computer models like GCMs and assumptions are powerful tools, but we must always be ready for the unexpected when it comes to climate change, inform ourselves well, and be ready to adapt. Perhaps this is the most important principle in the climate change toolbox: expect the unexpected.

Quiz 1

1 What region of the province receives the least amount of precipitation in a year?

a. Yarmouth **c.** Halifax

b. Greenwood **d.** Sydney

2 What region receives the most precipitation in a year?

a. Yarmouth **c.** Halifax

b. Greenwood **d.** Sydney

3 In what season does the most precipitation occur?

a. Spring **c.** Fall

b. Summer **d.** Winter

4 What is the hottest region in Nova Scotia?

a. Yarmouth **c.** Halifax

b. Greenwood **d.** Sydney

5 RCP scenario 8.5 is the best-case scenario for humans. ☐ **True** ☐ **False**

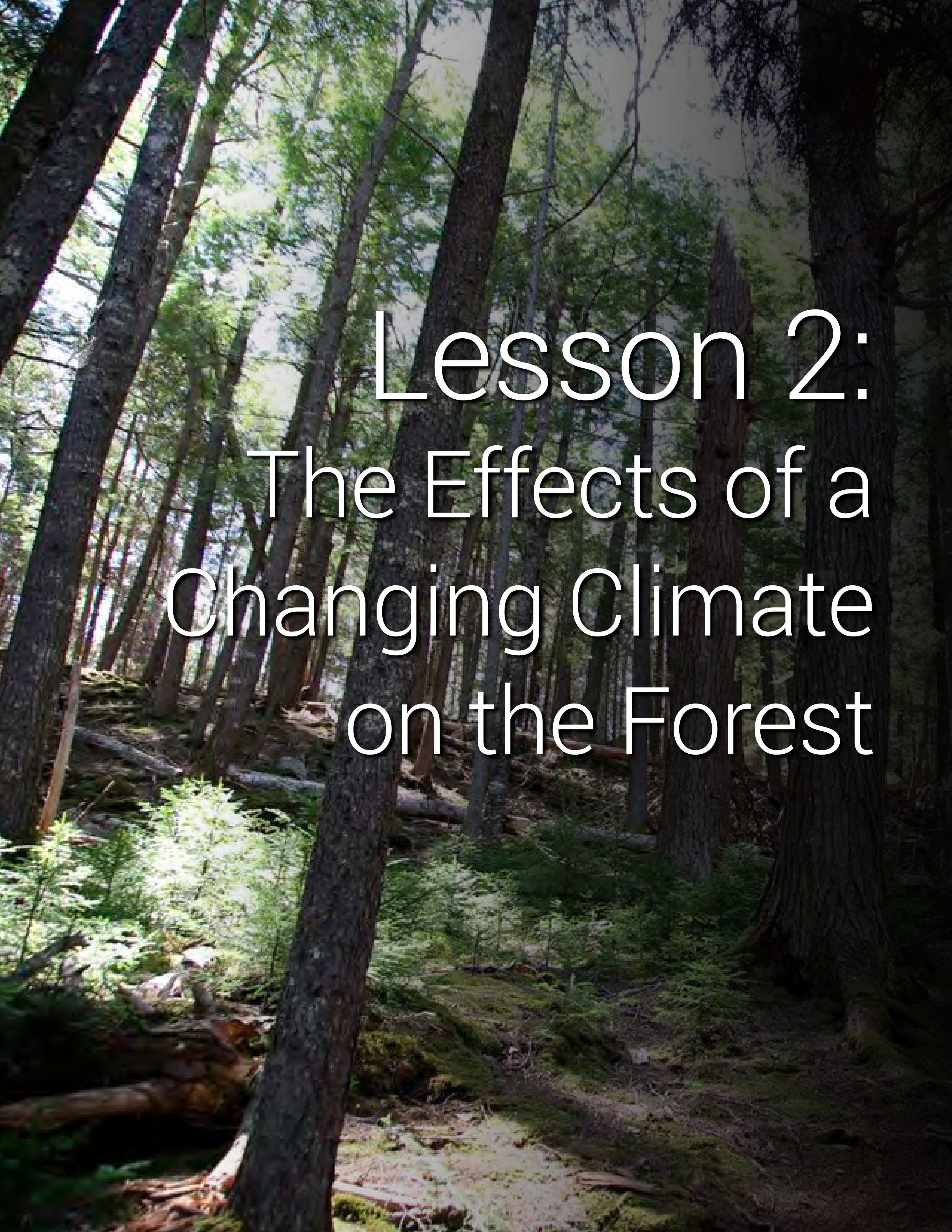
6 Temperatures are projected to increase in coming decades. ☐ **True** ☐ **False**

7 Precipitation is projected to come in the form of snow in coming decades. ☐ **True** ☐ **False**

8 Growing seasons and frost-free days are both expected to decrease in coming decades. (T/F) ☐ **True** ☐ **False**

9 We can easily predict the future climate patterns. ☐ **True** ☐ **False**

Lesson 2: The Effects of a Changing Climate on the Forest



Because climate change is very uncertain, its impacts on Nova Scotia's forests are also uncertain. Understanding more about how trees and forests will be affected is key. Do different kinds of trees respond differently to change? Are some species better suited to these changes than others? What changes can woodlot owners expect to see in coming years? In this lesson we will look at how different trees and forest types are expected to respond to some of the climate changes we've talked about such as changing precipitation and temperature patterns and more extreme wind events.

Effects of Increasing Temperature on Trees

Nova Scotia is known for its warm summers and relatively mild winters, which are caused by the moderating effects of the Atlantic Ocean – officially called the maritime effect. Our forests are accustomed to a relatively stable climate and changes in these regimes can have negative effects because they create conditions different from those under which the forests evolved over the past millennia. If the climate changes too quickly, tree species can become maladapted. As we saw in Lesson 1, rising temperatures will translate to longer growing seasons and earlier thaws. How will these shifts affect species composition and succession in our forests?

During extreme heat and limited water availability, some leaves on trees can experience scorch or sunburn damage.

Temperature Changes

Spring brings warm temperatures that encourage the development of new growth and flowering so that trees can thrive in the summer sun. However, extreme temperatures in summers could result in heat stress, disrupting reproduction and growth in trees. When trees – and plants more generally – experience **heat stress**, they close their **stomata** to prevent excessive water loss[32]. Stomata are tiny holes found on tree leaves that facilitate gas exchange between the tree and the air. This gas exchange is vital in absorbing atmospheric CO_2 and releasing oxygen during photosynthesis. A tree's inability to absorb carbon dioxide due to this closure disables its ability to photosynthesize.

Being unable to produce energy, plants will go into a dormancy and become stressed. This can prevent the tree from performing various tasks and may cause early or delayed flowering. This may further cause the male and female parts of trees to perform their reproductive tasks asynchronously, causing a general loss of reproductive capacity[33].

The flip side of the increasing temperature coin is potential increases in forest growth and productivity. Some of our native tree species are adapted to warmer climates (this will be discussed more shortly) and where they are abundant in a given ecosystem, the warming climate and longer growing season might translate to increases in growth rates. Such an increase could translate to more wood and more carbon sequestration, which is a positive change. However, it is generally expected that adverse impacts of climate change are likely to outweigh any of these productivity gains.

Disrupted frost-thaw cycles will cause problems for forests, machines, and people alike.

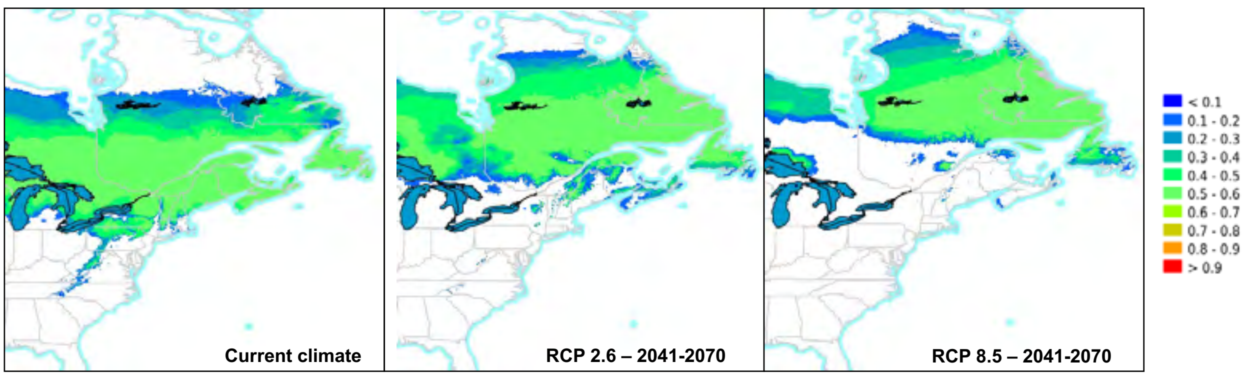
Abnormally warm temperatures in winter could also spell damaging effects for trees. Currently, **freeze-thaw cycles** play a role in influencing the development of our forests. Newly planted trees may suffer root breakage due to soil expansion during daytime highs and contraction during night-time lows. One may also recognize bark cracking on the south-southwest sides of trees. This occurs when bark expands in the sun during daytime, then contracts faster than other portions of the trees – causing it to crack vertically. This is especially common in non-coniferous trees. Late spring freeze events also kill new, tender shoot growth on trees and affect their future growth rates for the season, as was seen in the recent large June freeze of 2018. This freeze-thaw cycle will likely become disrupted in future, with freezes occurring at abnormal periods of the year[34].

Trees and other plants can also sense prolonged warming temperatures in winter and early spring and will produce new growth and may potentially flower. This could be a problem if this occurs after an abnormally warm February, for example. Trees may experience warm weather and unharden new buds, only to have frosts occurring in March kill off this new growth. So, while one may expect a longer growing season is coming our way due to earlier thaw events, the inability of trees to adapt to the abnormal start to these new cycles will initially disrupt tree growth in the short term. The abnormal frost that occurred in late June of 2018 wilted new growth of many kinds of crops, from Christmas trees to grapes[35].

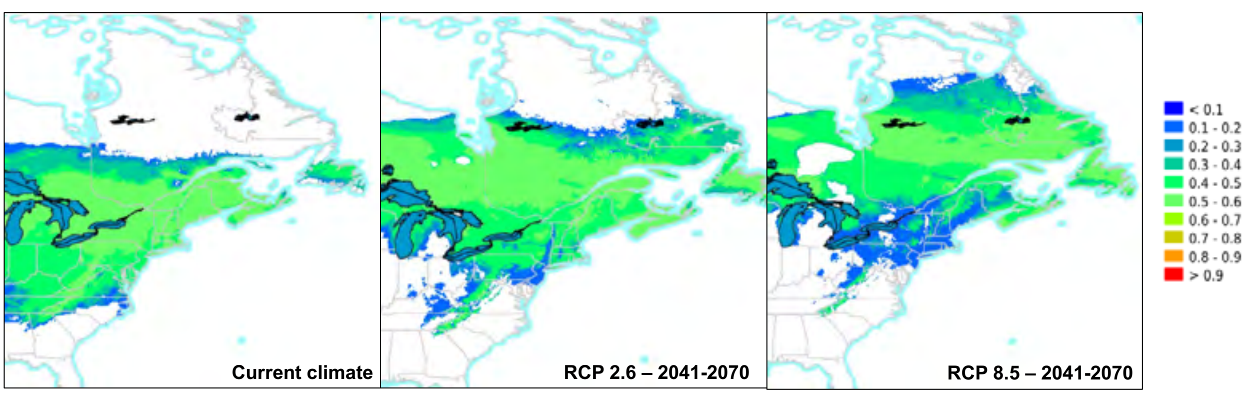
Climate Envelopes and Species Shifts

Nova Scotia's forests will not be affected equally by the impacts of rising temperatures. To explain, Nova Scotia is a part of the Acadian (Wabanaki) Forest Region and Atlantic Maritime Ecozone. This region is a transitional zone between the temperate forests to the south and boreal forests to the north. Many of the temperate-zone species here are near their northernmost (and coldest) limits of their range while many of the boreal species are near their southernmost (and warmest) limits. This climate-driven geographic range of a tree species is called a **climate envelope**[36].

A climate envelope is the range of temperature and precipitation a species may *optimally* grow in. Increasing temperatures could see the climate envelopes of our trees grow, shrink, or leave the province entirely. This is not to say that species will not exist outside of their respective climate envelopes, but they would likely experience difficulties in health and growth[37].



Shifting climate envelope of balsam fir under different climate change scenarios (figure credit: Natural Resources Canada, planthardiness.gc.ca).



Shifting climate envelope of white pine under different climate change scenarios (figure credit: Natural Resources Canada, planthardiness.gc.ca).

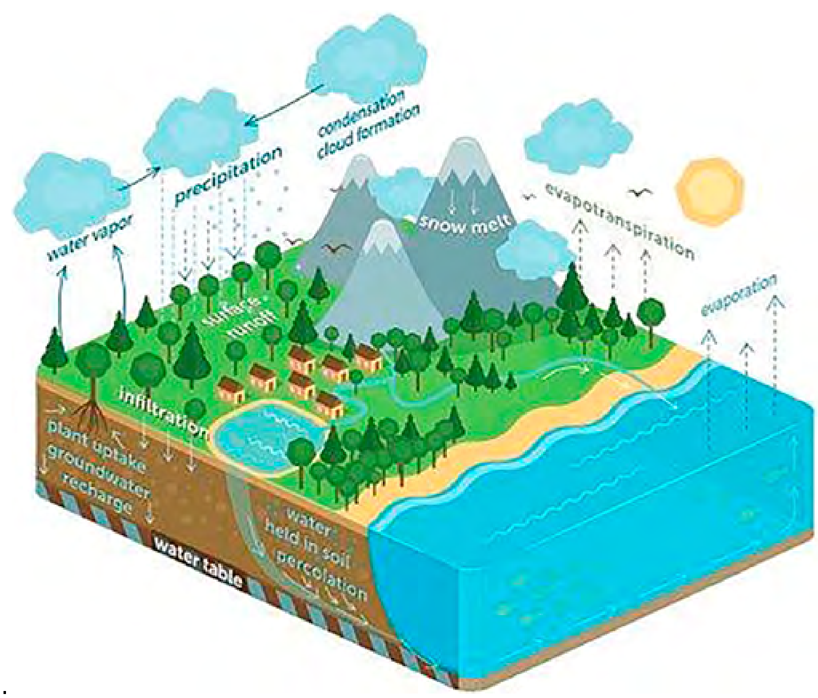
Over-generalizing to some extent, one may expect temperate species to fare much better with warming temperatures than boreal species because of the respective warmer and cooler climates of their entire range. Red maple, for example, has a climate envelope that extends as far south as Florida. We would expect that rising temperatures would simply impose conditions on Nova Scotia that southerly species may be productive in[38].

White pine, red oak, and eastern hemlock also have climate envelopes that stretch into warmer, southerly regions. Compare this to balsam fir, black spruce, white spruce, and white birch that have ranges extending across the boreal forest but not much further south or warmer than Nova Scotia. We may expect that with warming temperatures, these colder-climate boreal species will be at a disadvantage and even maladapted. Our provincial tree, red spruce, has a smaller range and climate envelope that is pretty much restricted to the Acadian Forest, which makes it vulnerable but also adds uncertainty to how it will respond to the warming temperatures.

These contractions and expansions in species' climate envelopes will not result in the immediate removal of various species in stands. The overall abundance and health of species in stands will be dependent on many different factors. Climate change in combination with management, site conditions, natural disturbances, competition, and succession will dictate the future composition of forests in Nova Scotia. Natural migration is a complex process for tree species. Without climate change, some species might have migrated northward at most 100 m per year, assisted occasionally by rare long-distance seed travel[39]. The rapid rate of climate change might exceed a species' ability to keep pace and within its shifting climate envelope.

Precipitation Patterns

Forests play a significant role in the water cycle. The roots of trees pull moisture from the soil. That water content and dissolved nutrients will be delivered through their tissue, known as **xylem**, upward from the roots to the leaves. When the water reaches the leaves, it is expelled through the stomata as a by-product of **plant respiration** or through **transpiration** in the form of water vapour. Together with the evaporation of moisture, the combined processes, called **evapotranspiration,** cool leaves, the forests, and the surrounding landscape. This process is important in the context of potential future droughts in Nova Scotia.



The water cycle in a forested landscape (figure credit: Food and Agriculture Organization).

In the future, Nova Scotia will likely see significantly more precipitation within the spring and winter months, a moderate rise in autumn, and only a slight rise in summer. Precipitation regimes are expected to change for both the moderate (RCP 2.6) and extreme (RCP 8.5) climate change scenarios. Many of the effects of changing precipitation will depend on the associated temperature changes. When studying the effects of changing precipitation, researchers often focus on the relationship between soil moisture and air temperatures rather than the total amount or frequency of precipitation. Trees and forests require more moisture to remain healthy as the temperature warms and drought stress can increase even if there is no decline in rainfall.

With warming in the winter months, the type of precipitation Nova Scotia is likely to see may also change. Instead of the snowfalls we are used to, one may expect to see more rainfall during winter months. This might result in higher amounts of freezing rain and wet conditions, which will result in even less snow cover. The reduced snow cover would further cause higher air temperatures because of the reduced reflectiveness of the ground's surface (called **albedo**). If the albedo is lower, the ground absorbs more solar radiation rather than reflecting it back to the atmosphere, which increases warming. This higher amount of winter rainfall can lead to more flooding and erosion, especially without the leaves on the broadleaf trees that help to slow down rainfall hitting the ground in large storms.

In addition to possibly causing runoff and soil erosion within stands, woodland owners may see vulnerability in road networks and forestry infrastructure from increased rainfall, especially in winter months.

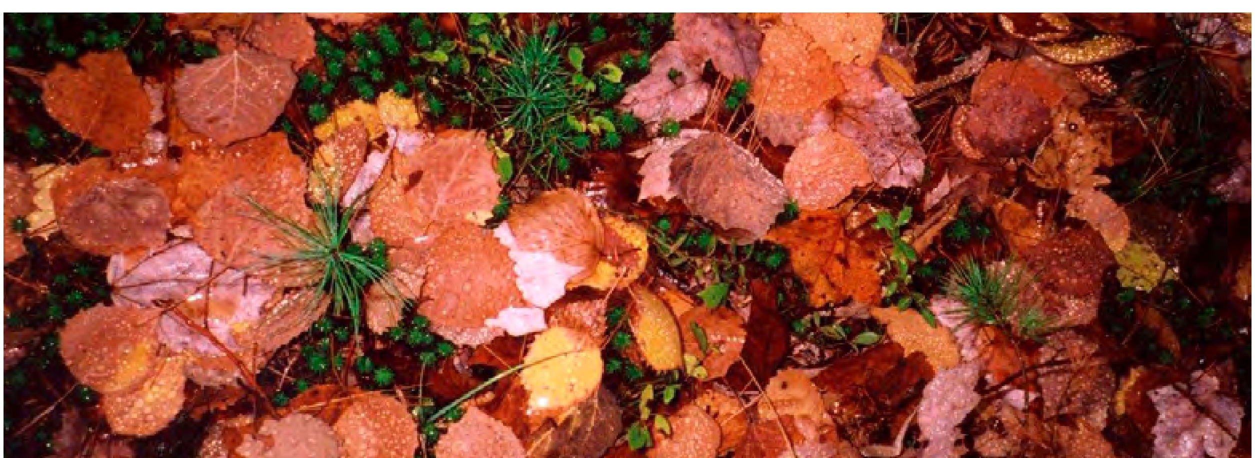
The impacts of a changing precipitation regime for forests also occur in the drier summer months. While rainfall amounts in the summer are predicted to be relatively stable, this rain may come in larger events separated by longer periods of dry conditions. This sort of precipitation regime can have negative effects on tree growth and resilience due to water deficit through longer periods of dry conditions. If there are large, short-duration rain events, flooding will become more frequent and soil erosion will accompany it.

Soil-Water Dynamics

It is important also to think about the way tree root systems will react to precipitation changes. Soil water is the only water available for uptake by trees. Tree roots ordinarily occur no more than 60 cm below the ground surface, with some species only occasionally penetrating slightly below the upper soil layers[40]. While water stress in trees may be more apparent in the leaves, it begins in the root system.

Soil moisture is that water content present in soils, excluding lakes, rivers, or groundwater. Its maximum potential quantity, partly determined by soil type and slope position, is vital in predicting possible drought and flooding risk. Soil moisture can be separated into two groups, surface soil moisture (up to 10 cm depth) and root zone soil moisture (less than 200 cm depth)[41]. Compare the two categories: regular smaller events contribute an even coating of precipitation over the length of a season. In lighter small events, root zone soil may be penetrated occasionally, and during larger events will be saturated. Water needs time to permeate through soil and reach lower levels of soil depth. If precipitation events are expected to be fewer and less frequent – especially in larger amounts over a shorter period – it will likely result in more runoff and less infiltration into the soil[42].

In addition to less moisture in deep soils, increased temperatures will drive higher evaporation and transpiration rates which, in combination with the precipitation patterns, will likely cause more drought conditions in forest soils.



The leaves of deciduous trees begin the process of decay among mosses and saplings.

Wind Regimes

While changes in temperature and precipitation are likely to be the main avenue of heat and water stress in forests, winds also play a major role. There are several ways in which wind can have negative effects on trees including effects on evapotranspiration rates, limb breakage, and blowdown. When we think of the effects of winds on our forests, our minds may immediately go to windthrow and limb breakage. These are major disruptive types of effects and will be discussed in-depth in Lesson 3. However, wind has more subtle yet important effects on how forests will react to changing temperature and precipitation regimes. The disruption of transpiration rates is closely related to how species will fare under increased temperatures and interrupted precipitation trends.

Wind can significantly alter transpiration rates both in winter and summer. In both seasons, high winds can worsen drought conditions caused by temperature and precipitation changes. Nova Scotia winds are expected to increase over time, with extreme wind events becoming increasingly common along with an increase in average maximum wind speeds. These increasing wind speeds will drive higher rates of transpiration both in winter and summer, reducing tree resiliency to drought conditions[43].

Winter desiccation is a common source of problems for evergreens, which remain active during the winter months. When prolonged cold temperatures occur, soils freeze or have insufficient moisture for roots to absorb. As a result, trees will lose more water through transpiration than they are able to absorb from soils. This effectively leads to winter drought conditions, which can have a wide range of effects including damage to foliage and developing buds or even mortality.

Trees and climate change – part of the solution…

Along with all the benefits that forests bring in general - cleaner air and water, richer soil, healthy biodiversity, erosion control, recreational and spiritual spaces, economic benefits - they are an important part of the equation in terms of helping to fight climate change for so many reasons!

They help to:

- absorb greenhouse gases
- capture and store carbon
- regulate water flows
- protect coastal communities from extreme events and sea level rise
- Provide landscape connectivity and cover for species forced to move as a result of habitat alterations caused by the impacts of climate change.

Increased winds can cause desiccation, with damage often occurring on the directional side of trees where the wind blows from most. However, these winter droughts may become less likely – especially by 2080, where average winter temperatures could reach -0.2°C under the RCP 8.5 scenario[44].

As mentioned, extreme heat and interspersed precipitation can cause drought conditions in summers. High winds during a hot and dry summer spell can significantly alter the evapotranspiration rates of forests, causing trees to lose more water than they can obtain through their roots. This will increase the effects of heat and water stress and disrupt tree growth. These drought conditions in summer can further reduce the winter resiliency of trees and may increase the chances of blowdown in extreme wind events.

Case Study One – Non-timber Forest Products

Bob and Diane live in Southwest Nova Scotia and tend several crops of mushrooms in the forest adjacent their home. Their woodland stand, composed of spruce, balsam fir, pine, maples, and birches, hosts several species of fungi that Bob and Diane sell at a local farmer's market. Together, the pair has operated their mushroom farm for several years, but trouble began in 2018. Shortly after winter, Bob and Diane noted a significant change in rainfall amounts. Instead of a regular shower here and there, they noticed that rain started to fall in long intervals. Their fungal crops began to show lower yields as a result, as fungi require moisture to produce mushrooms – their fruiting bodies. That moisture would have come readily in previous years from small, consistent rainfalls.

Bob and Diane looked over their yield and estimated a total loss of about 40%. This was a significant loss for them, and they noted a similar pattern in 2019.

To make up for the loss in their cultivated crop, Bob and Diane headed further into the woods – instead foraging for wild mushrooms to supplement their usual yield. However, because of the subpar precipitation regime, the spring harvest of wild mushrooms that was usually bountiful was now almost nonexistent in their woodland. Adapting quickly, in 2020 they began soaking the logs they injected with fungi. While Bob and Diane still to this day maintain logs filled with fungi under the protective canopy of conifer trees in their woodlands, they still must transport most of their crop-logs to a basin tub to soak and maintain moisture levels. In the changing climate of Nova Scotia, this sort of adaptability to changing environmental regimes will be vital to maintaining non-timber forest products.

Dry conditions and high heat are not conducive to the production of fruiting bodies of fungi.

Quiz 2

1 How do plants prevent water loss during high temperatures?

A. They close their stomata

B. They open their stomata

C. They absorb more water through their roots

2 Abnormal freeze-thaw cycles will have no effect on new growth and buds of trees. ☐ **True** ☐ **False**

3 What is a climate envelope?

A. The optimal environmental conditions that a species can persist in

B. The natural established range of a species

C. The environmental conditions that a species cannot inhabit

4 Species migration is a fast process. ☐ **True** ☐ **False**

5 How do plants transport water through their stems?

A. The phloem

B. Transpiration

C. Xylem

6 Transpiration is the process of expelling water vapour through stomata, which cools plants. ☐ **True** ☐ **False**

7 Where do most tree roots inhabit in soil?

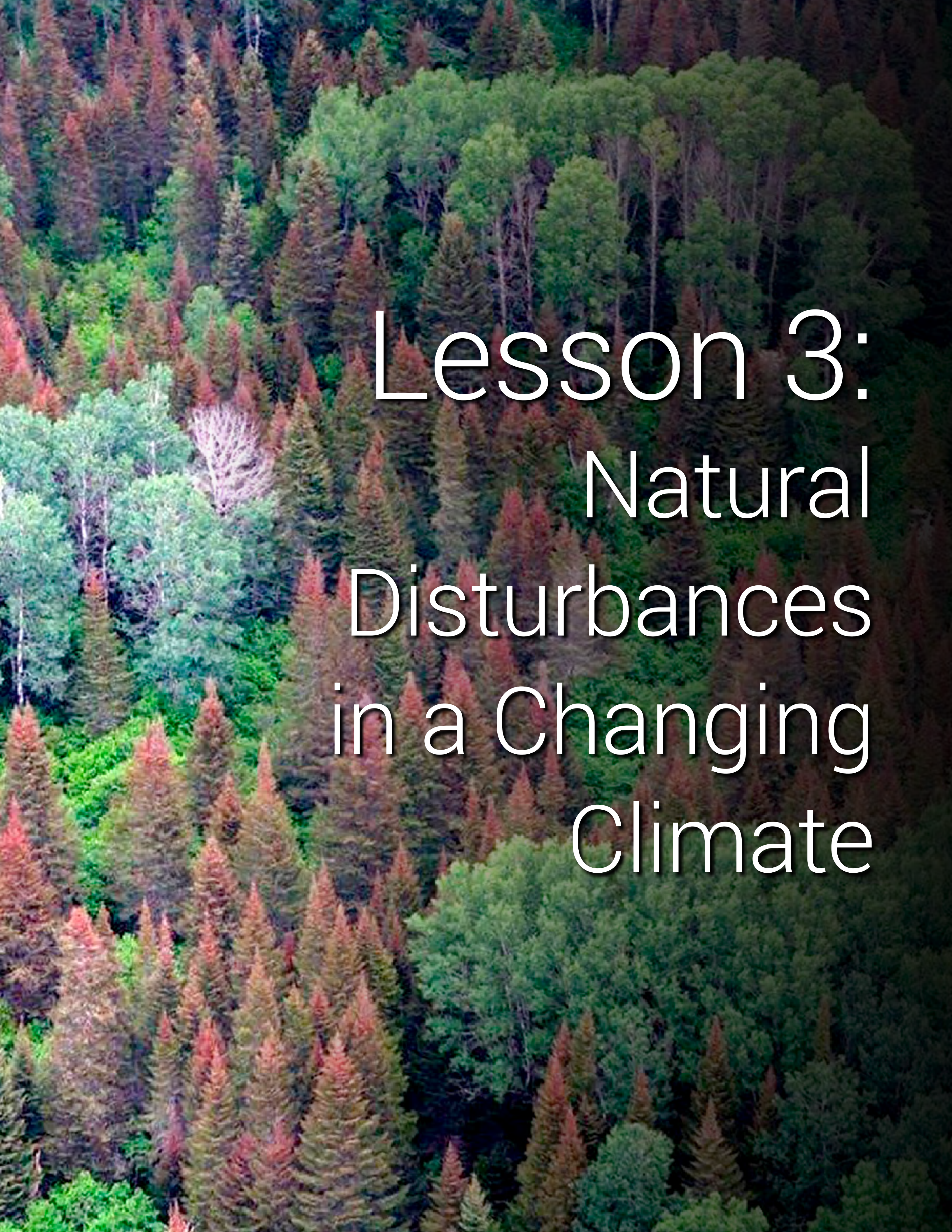
A. >60cm below the surface

B. <200cm below the surface

C. Evenly over 200 cm of depth

8 Drought conditions more likely to occur in future. ☐ **True** ☐ **False**

Lesson 3: Natural Disturbances in a Changing Climate



Natural disturbances are a fact of life in Nova Scotia's forests, and indeed forests everywhere. In this lesson, the objective is first to learn about how forest disturbance regimes may be influenced by climate change. Then the focus shifts to understanding how the various disturbance agents and regimes behave: fire, wind, insects, and pathogens. Finally, insight is shared on how the disturbance agents may interact as the climate changes.

Disturbance Agents

While humans have a long history of influence on the Atlantic Region's forests, natural disturbances are critical drivers of the forest ecosystems and biodiversity. Natural disturbances, such as wind, fire, and insects, are natural processes and in fact their occurrence helps maintain the Acadian Forest. In fact, there are ecological impacts from our removal of natural disturbances through activities like fire suppression and spraying for pests like spruce budworm. However, with climate change, the line between natural and man-made disturbances is becoming blurred. Rising temperatures from human-caused climate change will increase the frequency and severity of many of these 'natural' disturbances.

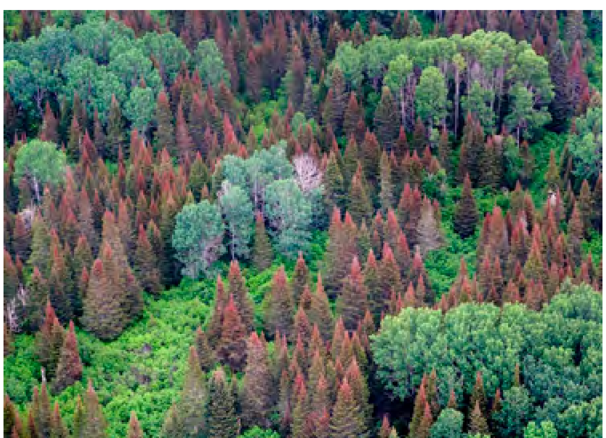
With that said, natural disturbances are drivers of change in forests. **Disturbance agents** are the causes of natural disturbance, such as wind, fire, and insect outbreaks. **Disturbance regimes** are their patterns over time, including the size of the areas they usually affect, how severely they hit, how often they return, and how long they last.

The agents may be **abiotic,** or physical, disruptions, such as windstorms or large wildfires. The occurrence of these disturbances is dependent on a diverse set of local conditions, such as temperature, moisture, soil type, and forest conditions, among other things. They are often the cause of large, **stand-replacing disturbances**.

Insects, fungi, bacteria, and viruses are examples of **biotic** disturbance agents. These often have smaller impact areas than abiotic disturbances, creating smaller openings in forest canopies called gaps. Despite this, they constitute a significant part of forest ecological processes because they can collectively impact the forest across a much larger range through **gap dynamics**. Both abiotic and biotic disturbances can create gap dynamics.

Biotic disturbances are much more selective in their impacts on tree populations than abiotic disturbances. For example, insects often target a specific species. Insect pests are separated into two groups: native and invasive alien species. **Invasive alien pests** have been introduced to an area in which they did not evolve, either through deliberate or accidental human means or even due to a changing climate. Warmer temperatures, especially in the winter, are allowing invasive alien pests like the hemlock woolly adelgid to become better established in the province. They may as also lack predators that would naturally keep their numbers in balance with their environment. Native pests exist naturally within Nova Scotia but are prone to population eruptions that can cause large-scale damage if an outbreak occurs, such as a spruce budworm infestation.

Pest species can come in two forms: **irruptive** and **chronic** species. Irruptive species explode in population size in response to environmental conditions before undergoing a bust cycle resulting from dwindling resources that are insufficient for maintaining their expanded population. An example of this would be the spruce budworm that undergoes fluctuations, or booms and busts, in population. Chronic species maintain small populations and persist over longer periods, such as the spruce bark beetle that tends to target senescent red spruce.



Defoliation caused by spruce budworm (photo credit: Government of Nova Scotia).

Major disturbance agents in Atlantic Canada include fire, wind, insects, fungi, and micro-organisms. **Fire, windstorms, hurricanes, and spruce budworm rank as the four dominant natural disturbance agents shaping the province's forests.** Flooding and drought can also have an impact on a local and less severe scale. These agents may have small to large effects on forests, ranging in extent of impact from a few trees to dozens or hundreds of hectares (even hundreds of thousands in the case of spruce budworm). Wind is the main source of natural disturbance in Nova Scotia and Atlantic Canada more broadly, though insects and pathogens also represent a significant source. *Natural* fire (i.e., started by lightning) was an important historical source of disturbance in Nova Scotia, though fire suppression has for the most part removed large fires as a disturbance agent. Most fires in Nova Scotia in recent years are small and human caused[45].

We must also consider the notion that disturbance agents frequently act together in a cumulative fashion to reshape the forests of Nova Scotia. A prime example is broad-scale windthrow (for example, Hurricane Juan) followed by fire (for example, the Porter's Lake fire). The fire was doubtless larger and more intense because of all the deadwood lying on the forest floor following Juan.

Disturbance Regimes of the Past and Future

Fires

While fire has played an almost equally important role as a disturbance agent since post-settlement times, historical records and observations point to humans as a main cause of fires in Nova Scotia. 11,000 to 6000 years before present, large widespread fires caused by lightning strikes played a major part in changing the composition of forests in Nova Scotia. In the last 6000 years, these events have become less frequent, but fire is still one of the main disturbance agents in Nova Scotia[46].

In the past 6000 years, Indigenous Mi'kmaw communities had local influence on fire occurrence in forests. Some literature suggests that the Mi'kmaq started forest fires to clear land for berry production and to provide grazing grounds for both moose and caribou. However, there is insufficient evidence to suggest that they had a substantial impact on regional fire regimes. Most widespread fire disturbances were ignited by lightning strikes. After the beginning of European colonization, several historical records suggest that large fires were made for land clearing purposes. In recent decades (~80 years), most fires were human-induced and only a few exceeded more than 25,000 ha, with most never exceeding 10 ha in size[47]. This is mostly due to fire suppression, which plays a major role in disrupting the severity and spatial impact of this disturbance regime. Between 6600 to 2200 years ago, intervals between major fires are thought to be around 400 years. Around 250 years ago, that interval was shorter at 100–200 years. Over the last four decades, average fires per year ranged from 220 to 450, and burned less than 2000-3000 ha/year[48]. Woodland owners can learn more about wildfire and managing their woodlands from Module 16 "Wildfire and Your Woodland" in the Department's home study program.

There are multiple factors determining the intensity of forest fires. Fire – in the woodstove as in the forest – is reliant on an ignition source, fuel, oxygen, and a favourable climate. In Lesson 1, we discussed how mean annual temperatures are projected to increase some 2.0-6.0°C. Lesson 2 discussed how these increasing temperatures will increase the likelihood of droughts in conjunction with lengthened intervals between precipitation events. These conditions would further be conducive to increased forest fires. The annual area burned in southern New Brunswick alone is projected to increase some fourfold near century's end, and the larger Atlantic region could see a threefold increase[49]. Less-severe climate change scenarios would have correspondingly smaller effects. However, many projections do not take into consideration the overall resistance of temperate non-conifer species such as maples and yellow birches which may be increasingly favoured by the warming climate in Nova Scotia's forests[50]. This is important if climate-change impacts on species composition occur and lead to an increase in broadleaved species in the long term.


Traces of a fire near Little Tobeatic Brook

Some species of trees are more adapted to fire regimes than others. In boreal forests, the primary source of natural disturbance is fire. Many coniferous tree species have adapted to the fire regimes, and several boreal species such as aspen, white birch, and jack pine readily reproduce after fire disturbances. Jack pine requires the intense heat resulting from a fire to release its seeds from the wax-coated cones (called serotinous cones), and species like white birch and aspen will re-establish themselves by stump-sprouting and root-suckering. The rough bark of several coniferous species act as fuel ladders for fires to reach the canopy, allowing the embers of canopy fires to spread via high winds to other stands. Some 40% of Nova Scotia's total forested area is characterized by the presence of balsam fir or black spruce. These two species are highly susceptible to fire damage which can be expected to increase in the coming 80 years.

Human-caused fires will always remain a major source of forest disturbance at a local scale with or without climate change, despite fire-suppression efforts and a general shift to fire-resilient temperate species. Lightning strikes, as will be observed below, are expected to increase due to an increase in atmospheric energy that causes thunderstorm formation.

Wind

One of the most significant sources of abiotic disturbance in Nova Scotia is wind. Disturbance from high winds is windthrow, in addition to stem or branch breakage. Winds reaching 50 km/h are common across Nova Scotia, particularly in coastal areas, but are unlikely to cause substantial windthrow.

The particularly strong winds of **hurricanes** can cause blowdown in the form of uprooted trees and broken stems. In September of 2003, partial stand damage from Hurricane Juan, for example, was observable across 600,000 ha of forest in the province, and full stand blowdown occurred across more than 91,000 ha. Hurricanes occur fairly frequently in Nova Scotia. Making landfall on Nova Scotia on average every seven years, these events can range in forest damage from forest canopy gap creation to windthrow exceeding hundreds of thousands of hectares[51]. Assuming no influence from climate change, a storm like Hurricane Juan would have a return interval of 750-1250 years[52].

A windthrown tree crashed into several younger stems, causing damage to the surrounding stand.

Hurricanes are not the only source of wind damage, however. Windstorms also influence forest structure by causing windthrow and stem breakages due to their 50-100 km/h winds. Windstorms come in the form of **extra-tropical cyclones** (ETCs) and **tropical storms**. ETCs typically occur between November and March and are commonly referred to as Nor'easters due to their dominant north-easterly winds, and track west to east across Atlantic Canada[53].

Combined with rain or snowfall, these extensive storms affect larger swathes of forest across the province than do hurricanes. Nova Scotia experiences an average of 40 windstorms per year, with only 2% of those generating sustained winds of >90 km/h[54]. Tropical storms, another class of windstorms, are slightly different. These track east to west and produce sustained winds of 56-104 km/h. If sustained winds reach above this threshold, they become classified as hurricanes. Between 1900 and 2019, at least 27 tropical storms have made landfall on Nova Scotia – one on average every four years[55].

Projections of wind disturbances for the Atlantic region are highly uncertain. However, some larger trends can be drawn between changing climate and storm intensity. Increasing air temperatures, for example, have been linked to atmospheric conditions that produce severe thunderstorms. This may mean larger and more intense downbursts. As well, increased sea-surface temperatures and increased evaporation in higher latitudes will increase the intensity of hurricanes likely to make landfall on Nova Scotian shores[56].

So, higher and more catastrophic wind conditions are projected for the future. However, a major part of how much damage these storms inflict depends on the ability of forests to withstand them. Windthrow is reliant on the lining-up of several attributes of both trees and wind. Some attributes that contribute to the risk of windthrow of a tree include soil type and root anchorage, tree species and size, and crown formation. Some species are more adapted to wind than others. White pine canopies, for instance, are less dense than spruce and balsam fir canopies and have needles that are long, narrow, and flexible. A higher abundance of non-conifers like maple and birch in mixedwood stands also significantly reduce the risk of stand-replacing windthrow. During Hurricane Juan, some firsthand accounts described conifer stands having >75% of their trees blown down except for the white pine component. Similarly, root formation and soil depth can have a big impact on a tree's ability to withstand high winds. For example, shallow-rooted spruces on a thin soil are much more vulnerable to high winds than deep-rooted non-conifers on the deeper soils of a drumlin hill[57]. Any kind of partial harvest silvicultural treatment can be informed by important wind vulnerability variables like soil type, exposure to high winds based on topography, and stand structure (e.g., tall, spindly softwoods with short crowns). These recommendations are described in the Silvicultural Guide for the Ecological Matrix[58].

While climate-change projections cannot fully account for how severe the disturbances presented by hurricanes will be in future, there is at least an understanding for the return interval for events like Hurricane Juan. As well, despite this uncertainty, we can grasp how susceptible forests may be to future windthrow because of species composition, tree and stand structure, and soil types.

Catastrophic windthrow caused by post-tropical storm Fiona (photo credit: Sean Power (left), James Steenberg (right)).

Thunderstorms are also common in Nova Scotia. These mostly occur in Atlantic Canada in the form of small downbursts but can be very intense over short periods. Compared to windstorms, they can occur frequently. With wind gusts exceeding 90 km/h, these occur some 5-10 times a year in Nova Scotia. Here, these events are recorded as uncommon and inflict minor structural damage in forests. However, in boreal forests and parts of New England, convective cells can result in small (100-1000 m^2) dispersed windthrow patches to severe windthrow events.

Insects and Pathogens

Historically, insect pests have had a greater impact on Nova Scotian forests than any other disturbance type. The primary source of biotic impact on the forests of Nova Scotia has come from spruce budworm, though other insect pests like the spruce bark beetle and white-marked tussock moth have taken a toll on the health of Nova Scotia's forests. Forest pathogens include viruses, bacteria, and fungi. Prominent examples include beech bark disease (an invasive fungal pathogen combined with a scale beetle), Sirococcus shoot blight, and armillaria root rot; these will be discussed shortly.

Spruce budworm outbreaks account for most of the natural disturbances from forest pests in the province. Despite the name, they target balsam fir first, followed by white, red, then black spruce all across Eastern Canada. Between 1967 and 1993, 50 million hectares of canopy in Canadian forests was defoliated by budworm, disrupting not only forest structure at a landscape level but also timber production and recreational and cultural values from forests[59]. At least seven outbreaks of the pest have afflicted Eastern Canada over the last 250-300 years, with spruce budworm accounting for the main source of natural disturbance in Cape Breton for the last two centuries. Historically, the forests of Cape Breton Island and Northumberland shore have been the most affected by spruce budworm outbreaks[60]. These stand-destroying outbreaks of spruce budworm tend to occur around every 30-50 years.

Larch sawfly, another pest species that has historically impacted Nova Scotia forests, tends to attack pure stands of tamarack trees, but can target isolated trees too. Defoliation from a year of feeding may have little effect on the longevity of trees, but chronic defoliation over many years can kill trees, as was observed in 1974 to 1977 in Nova Scotia.

Forest pathogens, (pathogen meaning a virus, bacterium, or fungus that causes disease) may affect a tree's vigour and cause decline or even mortality. In addition, many pathogens follow disturbances of other forms, like insects, environmental stresses, or animal grazing. Take beech bark disease, for example. Beech bark disease is the result of both a beetle and a fungus. Once the beetle has created a wound in the bark, the fungal pathogen then infects the wound. This creates cankers, pictured right, in which the scale insects then house themselves.

The cankers produced in beech bark because of the fungus provides shelter for the scale insect.

Another pathogen is armillaria, a root-rot fungus affecting a wide range of species in the Acadian-Wabanaki Forest. This pathogen can persist in a wide range of temperatures, but the condition for epidemic spread is warming. While not always stand-replacing or disruptive on a landscape scale like a hurricane can be, this pathogen can have detrimental effects on individual or small groups of trees. If infection occurs over several years, with no recovery and intervention from humans, fungal pathogens can cause tree mortality.

Biotic disturbance regimes of the future are variable and difficult to predict. Eastern spruce budworm populations, for example, will be affected by increasing temperatures. In the shorter term, extreme events like droughts will put stress on host-trees of this pest, making them more susceptible to infestation. Trees that lack what they need to be vigorous and healthy are weaker and more prone to damage and disease. This may result in larger and longer insect outbreaks. In the long-term future, however, spruce budworm populations may disappear from their southern range in Nova Scotia or may become restricted to higher elevations like in Cape Breton, as increasing winter temperatures result in higher mortality in juvenile spruce budworms[61]. In addition to this, the climate conditions are not likely to favour the major host tree species such as balsam fir[62].

The opposite may be true for other species – those same changes in climate may assist the intrusion of the invasive alien insect hemlock woolly adelgid in Nova Scotia. Increased winter warming and an increased number of frost-free days will likely further encourage the expansion of the range of this species in Nova Scotia[63]. Introduced into Virginia from Osaka, Japan, in the early 1950s, hemlock woolly adelgid has slowly expanded along the eastern coast of the United States. Its current distribution on the east coast ranges from northern Georgia to southern coastal Maine. Lower winter temperatures have thus far kept the woolly adelgid from erupting into significant outbreaks. Despite the pest only being discovered in Nova Scotia in 2017, it is now present across a third of the province.

The egg sacs of Hemlock Woolly Adelgid, which resemble cotton balls.

A changing climate's effect on host trees has more effect on a pathogen's ability to thrive in a changing climate than insect pests. Increased heat stress and water stress, and damage from natural disturbances, increases the likelihood of host infection by pathogens. Being weakened, many trees will be vulnerable to higher infection rates. Disease-inflicting pathogens are a minor disturbance in relation to abiotic agents and insect pests. While not always stand-replacing or disruptive on a landscape level, like a hurricane can be, these nuisance organisms can have damaging effects on individual trees or small groups of trees. In addition to altering a host's vulnerability to pathogens, climate change will also determine the reproduction of pathogens themselves. Many pathogens, like Armillaria, operate within a small range of climatic conditions. As a result, if climate change is drastic enough, some pathogens present now may not persist and could be replaced by others[64]. What species may replace them is entirely uncertain, as is ultimately the case when determining the future of species under climate change.

Interactions Among Disturbance Agents

A changing climate will heighten both heat and water stressors in forests and drought conditions may become more prevalent in future. In addition, heightened intensity of windstorms and hurricanes will result in increased windthrow. In this vein, natural disturbances regularly interact with each other through the effects they have on the forest. For example, increased water and heat stress will leave forests vulnerable to increased pathogenic activity and the related increase in temperatures could lead to the invasion of an alien pest species. This, paired with an increased rate of insects feeding on foliage in addition to windthrow from increasingly intense storms, may steadily result in increased tree mortality. That will increase fuels for forest fires. The increased fuel resource, paired with possible future drought conditions, may leave some forests susceptible to wildfires. As can be seen, natural disturbances are often cumulative and climate change may add strength to these interacting relationships.

Human management will also interact with natural disturbance agents in future. Management can directly change the age structure and species composition of forests, which in turn determines how susceptible forests are to various natural disturbances (especially wind disturbance). There is a myriad of different combinations of natural disturbance interactions that could become evident and more severe in a changing climate.

Quiz 3

1 What are the main natural disturbance agents in Nova Scotia?

A) Fire, wind, insects, and deer

B) Decomposers, noise, fire, and pathogens

C) Wind, insects, pathogens, fire

2 What are the two main groups of disturbance agents?

A) Biotic and abiotic

B) Symptomatic and asymptomatic

C) Natural and anthropogenic

3 What is and will be a major deterrent of fire disturbance?

A) Reduced amount of lightning in future

B) Fire suppression

C) Land-clearing

4 Pathogens can readily infect a healthy unstressed tree without problems — ☐ **True** ☐ **False**

5 Insects like spruce budworm have been a significant source of disturbance for the forests of Nova Scotia — ☐ **True** ☐ **False**

6 The spatial extent of forested land affected by fire may triple by century's end. — ☐ **True** ☐ **False**

7 Hurricanes will become more intense under a changing climate. — ☐ **True** ☐ **False**

8 Despite being uncertain, insect pests like hemlock woolly adelgid are likely to become more commonly distributed in Nova Scotia — ☐ **True** ☐ **False**

Lesson 4: Adaptation – Reducing Vulnerability using Best Management Practices

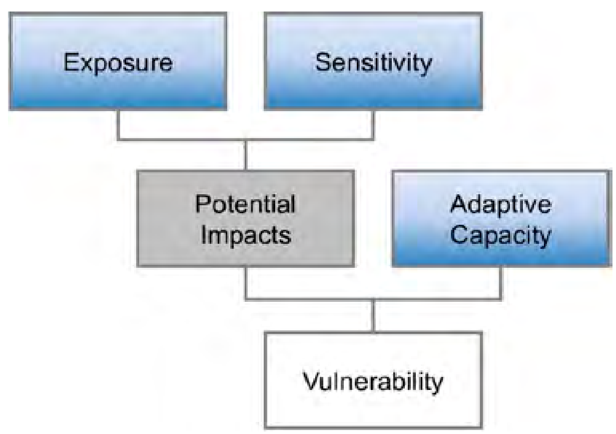
No matter how well and quickly we all reduce GHG emissions to the atmosphere, there will still be considerable global climatic change of sufficient magnitude to affect our forests. This means that successful forest management through the 21st century will need to account for how the changing climate may affect woodlands in Nova Scotia. In this lesson, the first objective is to learn about the concept of vulnerability and how it is useful in thinking about climate change and forests. Then readers are introduced to the concepts of ecological forestry and the triad and how implementing them can help the forests cope with climate change. Understanding how silviculture – particularly regeneration, tending, and harvesting – can help improve forest resilience in the face of a changing climate is the final objective.

Vulnerability

Humans influence almost every ecosystem on Earth at some level. Thus, when thinking about how vulnerable our forests are to climate change, we must consider both economic and social influences on natural resources as well as ecological factors. In defining the vulnerability of a forest to climate change, three major elements are considered: exposure, sensitivity, and adaptive capacity[65].

Exposure is defined as the nature and extent – i.e., the duration, magnitude, and frequency – of stressors to which a forest is exposed[66]. In the case of the forest and its management system, this would include precipitation and temperature shifts as well as natural disturbances.

Sensitivity includes the characteristics of the stand that determine how it may be affected by the exposure[67]. Components of sensitivity in a forest stand could include forest age, structure, and species composition. For example, even-aged mature stands composed of shallow-rooted species are more sensitive to wind exposure.



The components of vulnerability (figure credit: Marshall et al., 2009).

Adaptive Capacity describes the ability of a system to persist or change in response to stressors[68]. Management practices can promote the adaptive capacity of stands through harvesting and retention of species that will fare well in a warming climate or that are resilient to certain pests. Some environmental characteristics affecting the adaptive capacity of a stand could include soil structure, rooting habit of tree species, and continuity of forest cover.

Assessing the vulnerability of both forests and forest management systems in Nova Scotia can be done by woodland owners and managers using either quantitative or qualitative approaches, or, better yet, some combination of the two. In both kinds of approach, woodland owners and managers will need to consider both the spatial and temporal scope of stressors. Priorities and management decisions are ultimately decided by the values and objectives of woodland owners. Vulnerability assessments cannot properly indicate priorities for management, but they may improve the information base that landowners draw upon to support their decision-making[69]. The Canadian Council of Forest Ministers has a number of resources for vulnerability assessment that may be helpful, such as this **learning module**.

Ecological Forestry and The Triad

Ecological Forestry

In a rapidly changing climate, several management strategies need to be at the ready to adapt the forests of Nova Scotia. Managers will need to be capable of adapting to new scenarios quickly and in conditions of high uncertainty. **Ecological forestry** is increasingly being implemented in Nova Scotia and while it was not designed specifically as an adaptation to climate change, it provides many opportunities for doing so. Ecological forestry aims to maintain timber harvest values while prioritizing biodiversity and broader ecological values[70].

Ecological forestry focuses on the use of uneven-aged management that emulate natural-disturbance patterns. Stands with diverse structure and composition will likely be more climate-resilient[71]. Promoting a diversity of age classes promotes resiliency of the larger stand to climatic change and increasingly frequent disturbances.

Ecological forestry is in some ways a nature-based approach to hedging your bets by promoting a diverse range of species and structures.

Drone imagery of gap and continuous cover irregular shelterwood harvests in Antigonish County (figure credit: James Steenberg).

Ecological forestry aims to emulate the "normal" occurrence of natural disturbances which we understand from the study of *historical* disturbance regimes. However, we also know that these regimes are changing with the climate. If natural disturbances are expected to occur more dramatically and frequently due to a changing climate, the approach of ecological forestry will have to be modified to account for this. Until more reliable knowledge suggests otherwise, forest ecologists expect that continuing to emulate historical natural disturbances in forestry will help to maintain biodiversity and timber values through rapidly changing climatic conditions. Nevertheless, it is likely to be necessary to layer in different adaptation approaches into ecological forestry in the future.

The Triad

The triad approach to forest management was adopted recently by the provincial government following recommendations from the 2018 Independent Review of Forest Practices. The triad approach divides Nova Scotia's forests into three zones: a zone for conservation (i.e., without timber harvests), a zone for high-production forestry, and the surrounding ecological matrix zone[72]. The ecological matrix constitutes the largest zone where ecological forestry will be practiced maintaining ecological and economic values in balance[73]. The conservation zone would be set aside to prohibit industrial activities and will be core features of protecting biodiversity in the province[74]. The high-production forestry zone will be intensively managed to produce timber products, thus helping to alleviate the loss of timber production from the other zones[75].

The major objective of the triad is to encourage as much conservation of biodiversity and ecological values as possible without detracting from the economic benefits from the larger forest. Each zone within this land management paradigm has different advantages in the face of a changing climate. The ecological matrix will have a lighter touch with a focus on increasing forest resilience to climate change[76]. On the other hand, the high-production forestry zone will provide a wider range of management tools to promote adaptation. Shorter harvest intervals and intensive management regimes will give managers a quick reaction time to accommodate potential shifts in climate and natural disturbances. Its reliance on planted trees also allows for planting climate-adapted species and provenances. This falls under the umbrella of **assisted migration**. Assisted migration refers to the moving of seed or species from one area to another that is expected to have similar environmental conditions as the source area under a changing climate[77].

The diverse traits of the three zones will enhance the ability of a manager to adapt woodlands quickly to a changing climate. In an uncertain future, a wide range of tools to promote climate resilience is important. The triad is becoming a requirement on Nova Scotia's Crown land. For private landowners, there is no mandate for committing land to any one portion of the triad, but there may be benefits to taking this nuanced approach to woodland management.

Silvicultural Tools that Might Increase Forest Resilience

Diverse silvicultural practices are available for woodland owners for improving the resiliency of their woodlands. The two major types of silvicultural systems are uneven-aged and even-aged systems. Readers may recall from Learning Module 18 that uneven-aged systems are of three types: multi-aged, all-aged, and two-aged. All silvicultural systems can make use of tools that could potentially promote stand resilience.

Natural Regeneration and Planting

Two classes of triggers can reset forest succession: management treatments and natural disturbances. Forest succession is, in simplest terms, the natural progression of dominance of species in a stand. It is dependent on three conditions: state of the environment; species availability; and species life history and biology (called silvics)[78]. When it comes to species availability, tree species have different tolerances to shade and underground competition; the range is from intolerant (usually pioneer species – those first to establish themselves after a disturbance) to intermediate to tolerant (usually long-lived). If the disturbance is fairly severe, intolerant species like aspen, white birch, and pin cherry can become abundant. As the stand ages, intermediate and shade-tolerant species, i.e., those adapted to regenerating and growing under the canopy of other trees, and are often long-lived (e.g., hemlock, red spruce, yellow birch and sugar maple) begin to outpace and crowd out pioneer species. However, nutrient-poor sites or sites with too much or too little moisture in the soil often do not favour longer-lived tolerant species.

Balsam fir, spruces, and pine saplings regenerate an opening several years post-harvest

In addition to a range of site characteristics like soil nutrients and drainage, another factor that can influence forest succession is which tree species are present in the overstorey or nearby to serve as seed sources. While natural regeneration is often a preferred option for regenerating forests, seed sources of the species that would grow well on that site may be lacking or absent due to previous harvests. If forest stands are allowed to regenerate naturally with no human intervention, species otherwise vulnerable to climate change may continue to dominate the landscape[79].

Landowners may choose a more hands-on approach to support regeneration in a stand by planting trees of desired species. One can implement planting regimes (as described in Learning Module 5) to achieve a mix of species more adapted to warmer conditions. Woodland owners must evaluate the consequences and benefits of species selection. For example, red maple may flourish in a warmer climate because its natural range extends south all the way to Florida but managing a woodland to be dominated by red maple may come at the cost of biodiversity or timber objectives of the owner.

Tree species that are more adapted to colder, more boreal climates that will likely struggle in the warmer climate include balsam fir, white spruce, black spruce, white birch, tamarack, and jack pine. Species that are more adapted to warmer climates and may even benefit from a warmer climate include red maple, red oak, eastern hemlock, beech, and white pine. Lastly, species that tend to have more intermediate vulnerability include red spruce, yellow birch, sugar maple, and various poplars. There are, of course, high levels of uncertainty with these predicted vulnerabilities.

Relative vulnerability of Nova Scotia tree species to climate change[40,41]

Species	Relative Vulnerability to Climate Change
Red spruce	Intermediate
Eastern hemlock	Low
White pine	Low
White spruce	High
Black spruce	High
Balsam fir	High
Red pine	Intermediate
Jack pine	High
Tamarack	High
Sugar maple	Intermediate
Yellow birch	Intermediate
White ash	Low
Red oak	Low
Red maple	Low
White birch	High
Trembling aspen	Intermediate
Large-tooth aspen	Intermediate

Woodland owners should also think beyond tree species and look to genetic variability within a given species. Populations of trees have different genetic traits like growth rate, cold hardiness, and drought tolerance. These traits are usually shaped by adaptations to local conditions – and in a changing climate those conditions will change. Future adaptation might include taking seed sources from a warmer part of a given species' range and planting them locally in anticipation of a warmer climate. Such a strategy will be important for adapting and conserving species that are vulnerable to climate change but that we want to retain on the landscape, like red spruce. **Provenance trials** are an example of an adaptation on this subject and essentially take a representative seed stock of naturally occurring species and relocate them to another part of their climatic range where conditions may be optimal for growth[80]. In addition to this, in commercial stands, seed stock genetically tailored to be more resilient to shifting environmental conditions and possible diseases or insect disturbances may be a viable option.

Planting is not limited to stocking a recently cleared site. **Ecological restoration** can be conducted through the planting of long-lived species, such as red spruce, eastern hemlock, sugar maple and yellow birch, often referred to as shade-tolerant species due to their ability to grow slowly under a closed canopy. Planting these species can help to restore the site to pre-settlement conditions. This may be dependent both on pre-harvest site conditions and the type of harvest implemented[81].

Professional foresters and government agencies can assist woodland owners in understanding the forest ecosystem classification system, a woodland management tool that helps to point to the forest types that the stand conditions and site characteristics could naturally support. Woodland owners can also get assistance in producing an ecological management plan for their stands. Some examples include the Family Forest Network[82] and Department of Natural Resources and Renewables[83].

Tending After Regeneration

Tending is a type of silviculture treatment that can assist woodland owners in climate change adaptation. It can include commercial and pre-commercial thinning, crop tree release, and weeding. While the level of wind firmness varies across species, woodland managers can increase wind firmness with pre-commercial thinning treatments. In a naturally regenerated stand, trees are likely to seed in at high densities. As they compete for light in these higher densities, they develop shorter crowns and poor **height-to-diameter ratios** – meaning they are tall and spindly. These trees are sensitive to windthrow[84]. Pre-commercial thinning can be used to target both climate-adapted and windfirm species but will also grow windfirm trees that have larger crowns and better height-to-diameter ratios. Both pre-commercial and commercial thinning can also reduce the uptake of water from the soil as there are fewer trees remaining, promoting water-stress resilience in future drought conditions.

An operator conducting a commercial thinning regime in a conifer stand.

Crop tree release can also be used to promote the growth of trees more adapted to warmer climates. By grooming the forest immediately surrounding individual trees for acceptable growing stock and/or less-vulnerable species, woodland owners can immediately facilitate the enhanced growth of optimal species. Some caveats include only removing those trees shading the crop tree or touching the crown of the crop tree, as well as leaving the stems to the south side of the tree untouched to alleviate potential wind damage[85]. Similarly, though at a level very close to the ground, weeding is an effective tool in promoting the growth of saplings. Just as one might do in their garden, removing herbs and bushes that may crowd saplings in managed woodlands is a helpful way to promote suitable growing conditions prior to the application of thinning regimes later in a stand's development[86].

Harvesting Systems

After growing a stand for a desired length of time, an owner may decide to do a timber harvest. As mentioned above, two major silvicultural systems exist – uneven-aged and even-aged. All silvicultural systems can implement tools to promote climate resilience in stands. A lack of structural complexity in stands, like that found in even-aged stands, can make woodlands vulnerable to more regular and heavier disturbances from wind and insects. Maintaining structural complexity in stands can also promote species diversity through the creation of varied environmental and light conditions. However, woodland owners should always consider the windthrow hazard of a given site based on exposure and soils, as stands following partial harvests are more vulnerable to windthrow, especially shortly after the harvest.

Retention refers to leaving behind a certain portion of trees during harvests. This can be a useful tool in providing some ecological continuity in the harvested stands. In addition to being of particular importance in restoration efforts, retained trees provide diverse habitats and serve as sources of genetic memory of pre-harvest conditions for future stock.

A single-grip harvester conducts a group selection harvest in a red spruce dominated stand.

In Nova Scotia, all-aged systems are conducted in the form of single-tree selection harvests and group selection harvests. In single-tree selections, a uniform mix of age classes is maintained through the maintenance of at least four age-classes under a continuous overstorey of mature trees. A group selection harvest acts in a similar fashion to that of single-tree selection, but groups of similarly aged trees are targeted for extraction. A retained continuous overstorey promotes the establishment of long-lived tree species that are fairly tolerant of shade (i.e., LIT species, which means long-lived intermediate to tolerant species), or species that are adapted to warmer conditions. In addition to providing opportunities for transitioning to warm-adapted species, the structural diversity in the resulting stand may afford some resilience to natural disturbances that even-aged silviculture might not[87].

Multi-age harvest regimes in Nova Scotia can also be conducted through **irregular shelterwoods** that maintain at least some overstorey of mature trees and at least two age classes. This system can provide high adaptive capacity to managed woodlands by enhancing stand resilience. The irregular design of these treatments allows for adaptation measures to be woven in, like targeting vulnerable species for removal and harvesting gaps in place of a continuous-cover harvest to build resilience to wind disturbance.

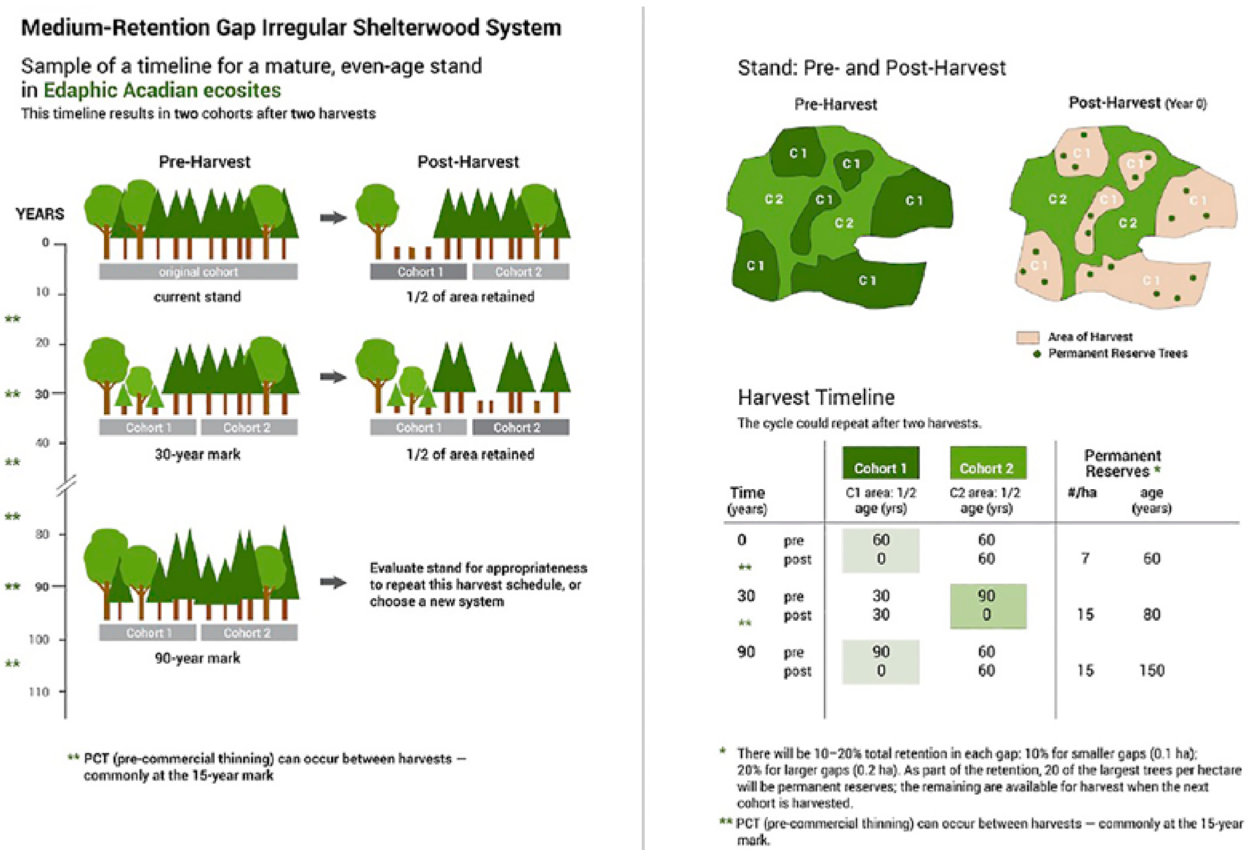


Diagram of an irregular shelterwood treatment that use using the gap style at a medium retention level. Overviews of these treatments can be found in the Silvicultural Guide for the Ecological Matrix (image credit: NSDNRR).

Case Study Two

In Nova Scotia, Jon manages a 90-ha forest where he implements gap irregular shelterwoods. Jon realized that if natural disturbances are going to become more intense in future and some of the species in his woodland may not fare very well, he should start preparing his forests for it now. Harvesting about a third of the stand in every entry, he makes 0.1 to 0.2 ha cuts. Groups of trees or single trees are maintained in each of his gaps to ensure the retention of seed trees and shade. Jon realizes he has a good stock of red oak and white pine in most of his woodlands. He reasons that he could quickly establish a robust population of longer lived species that will be adapted to the warmer conditions projected for his region by leaving behind oaks and pines during his harvests and focusing on removing the less adapted black spruce that are present.

Red oak saplings can be seen growing in a space opened after a gap harvest.

The retention of these trees also provides some shade for mid-tolerant and shade-tolerant species to compete with shade-intolerant species, allowing Jon to naturally regenerate his target species. While the gaps regenerate, Jon returns occasionally to thin the stand, promoting a species mix he knows is appropriate for the site and the future. This also promotes wind-firmness in the remaining stems. After 20 or 30 years, he returns to remove another third of the stand, but this time cuts adjacent to his previously harvested stands. This creates a new series of gaps beside the young forests regenerated from previous gaps, which creates new cohorts and adds stand complexity, increasing its resilience.

A mixedwood stand after a gap irregular shelterwood harvest.

Quiz 4

1 What are the three general components that can determine the vulnerability of a stand?

A. Exposure, sensitivity, adaptive capacity

B. Exposure, roots, tree height

C. Sensitivity, stem width, species composition

2 Species diversity and structural complexity (multiple age classes) can increase the adaptive capacity of a stand to various disturbances, like wind, insects, and pathogens. ☐ **True** ☐ **False**

3 What has more adaptive capacity to winds?

A. Trees with deep roots **B.** Trees with shallow roots

4 Provenance trials can be used to move genetic material of specific species that can fare well in a changing local climate ☐ **True** ☐ **False**

5 Thinning decreases wind-hardiness ☐ **True** ☐ **False**

6 What are the main ways that harvest systems like irregular shelterwoods can promote resilience in stands? Choose all that apply.

A. Promoting the establishment of intermediate and highly tolerant species throughcontinuous canopy cover.

B. Allowing retention of long-lived, intermediate-to-tolerant (LIT) species to promote the establishment of saplings of these species.

C. Producing varying age structures.

D. Promoting species diversification through varying age structures.

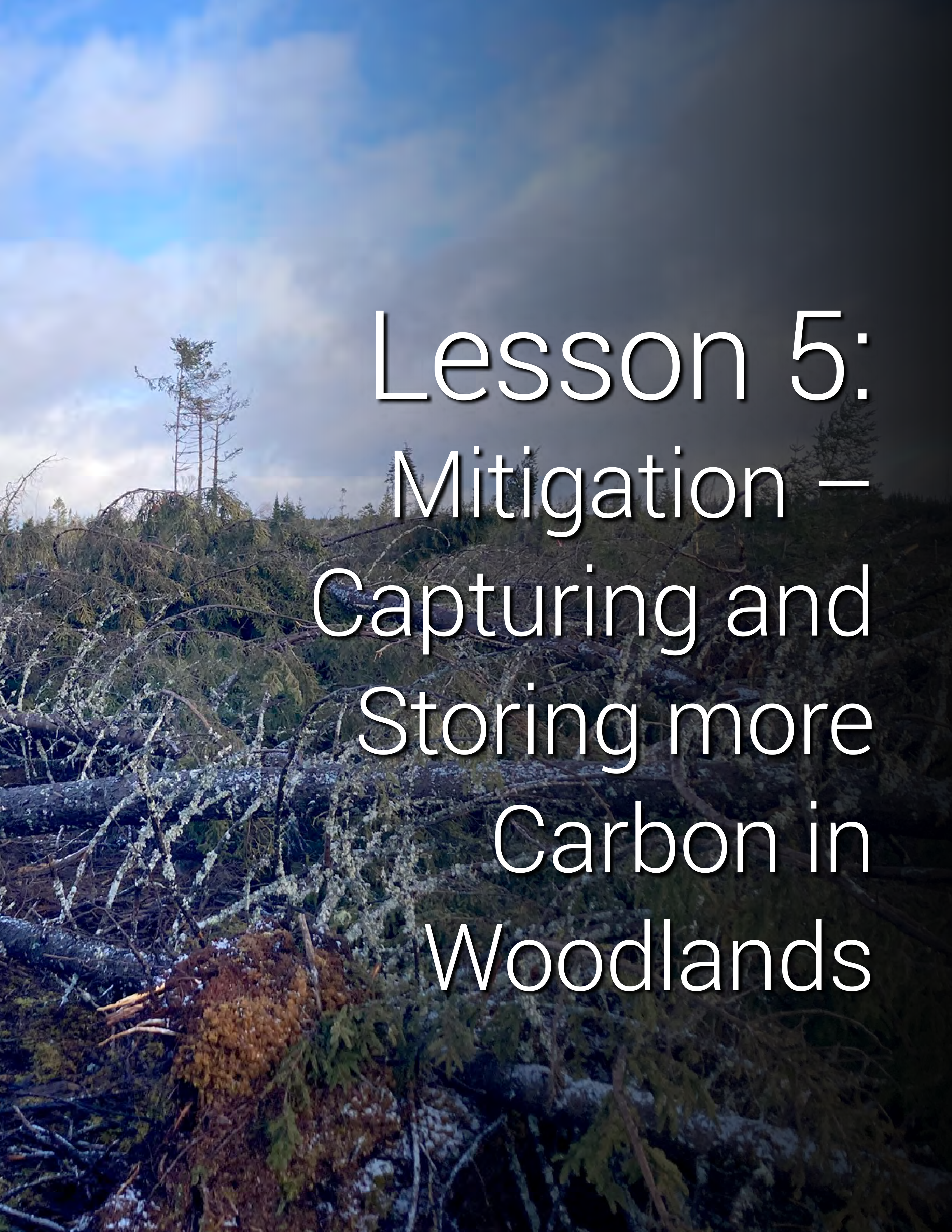
E. Reducing canopy cover to ensure light levels increase.

7 What are the three principles of ecological forestry?

A. Retention of legacy trees, intermediate treatments, and emulation of disturbance-regime return intervals

B. Planting, uniform thinning, and even-aged harvests

8 The three zones included in the land triad are: The Ecological Matrix, The Protection Zone, and The High Production Forestry Zone ☐ **True** ☐ **False**



Lesson 5: Mitigation – Capturing and Storing more Carbon in Woodlands

Forests are important in the global carbon cycle. This lesson covers some details about that fact and presents ideas on how to manage woodlands to increase carbon capture and storage. It covers various silvicultural techniques that influence forest carbon stocks, and also gives information on how forest carbon markets operate.

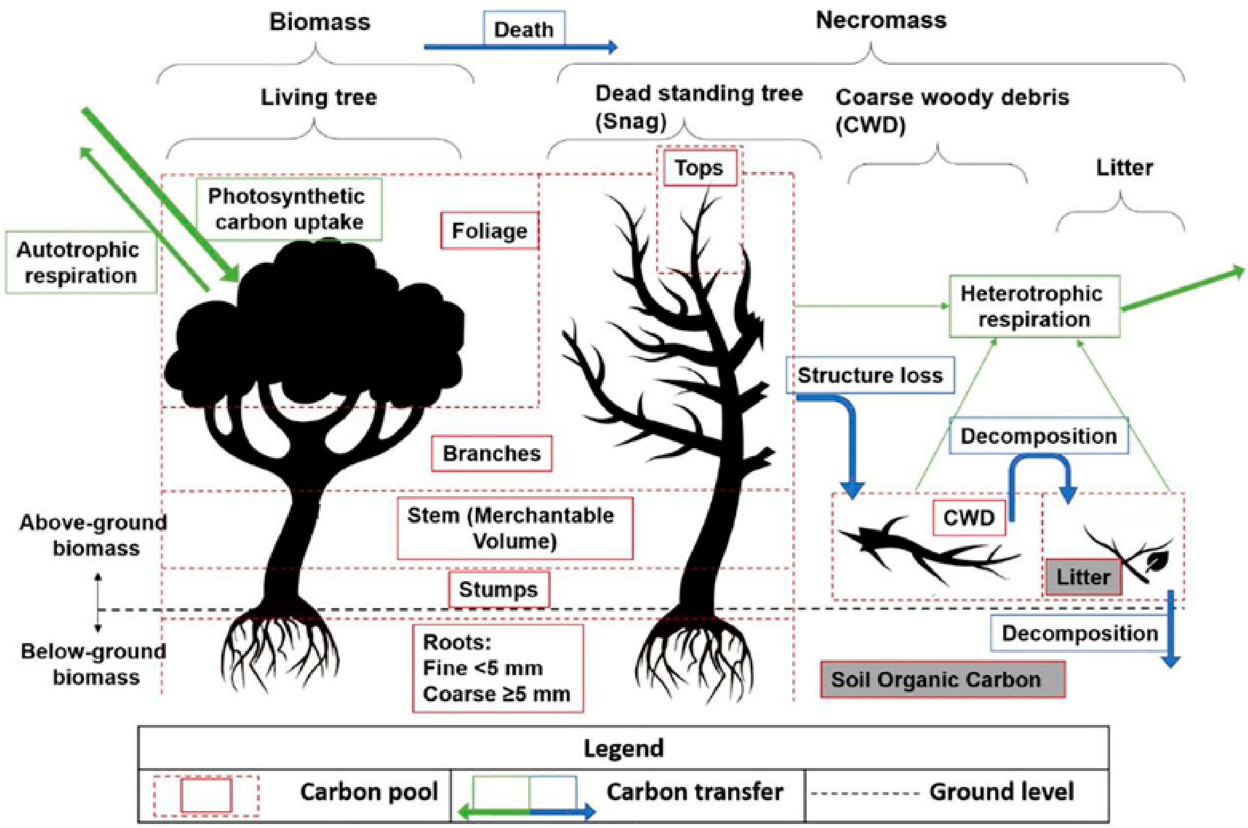
Woodland carbon and the forest carbon cycle

Greenhouse gas (GHG) emissions and increasing concentrations in the atmosphere mainly in the form of carbon dioxide (CO_2) are the leading cause of global climate change. However, carbon is a building block of life on Earth, as most living things on our planet are at least in part composed of carbon. **The carbon cycle** describes the flows and pools of carbon across the Earth's ecosystems, including living material (i.e., biota), soils, water, and of course the atmosphere.

As noted in the introduction, forests cover approximately 30% of the Earth's continents, and over 75% of Nova Scotia. Because of this, the state of our forests has major effects on the larger climate as massive reservoirs of carbon. Deforestation is one of the leading causes of climate change precisely because of increased flows of carbon to the atmosphere. At a global scale, forests help maintain earth's **carbon balance**.

When thinking about woodlands, we can identify two major pools of carbon storage: **living biomass**, including trees, shrubs, and other organisms, and **dead organic matter**, including snags, woody material, litter, and soils. Forest carbon is also stored outside of the forest in manufactured timber products, also considered dead organic matter, that have differing shelf lives. Both of these pools store carbon but living biomass is the only pool that accumulates carbon through photosynthesis and forest growth (in other words, sequestration). Roughly half of a tree's dry weight is carbon. While the amount of dead organic matter on the forest landscape can indeed grow over time and help fight climate change, any given piece of dead organic matter – whether it be a piece lumber or deadwood – can only release carbon to the atmosphere, and that is through the process of decomposition.

A more detailed look at the forest carbon cycle shows that atmospheric CO_2 is captured through photosynthesis and stored in a tree's foliage, branches, stems, and roots. Trees regularly shed foliage and small amounts of bark and limbs, which become dead organic matter in the form of litter and woody material on the forest floor. When a tree dies, it may remain standing as a snag for a period of time or fall to the forest floor. As this dead organic matter decomposes, most of its stored carbon is released to the atmosphere. However, a smaller portion of that carbon cycles through the forest floor and becomes part of the soils. Over centuries and millennia, forest soils have accumulated vast amounts of carbon – often more than the trees and other plants growing on them.



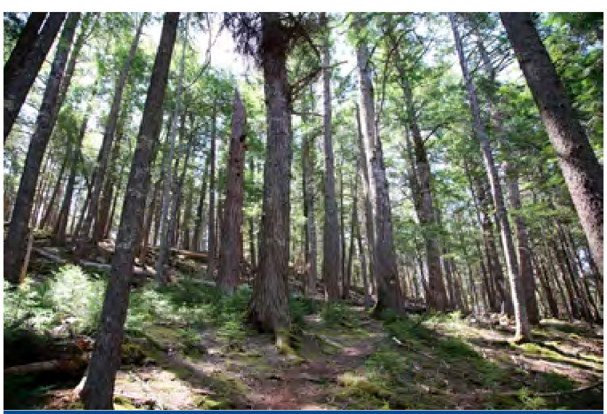
The forest carbon cycle, as depicted by a recent scientific study on forest carbon in Nova Scotia (figure credit: Jason Heffner45).

If the combined sequestration and storage of carbon in living biomass and dead organic matter accumulates over time, the forest is considered a **carbon sink**. On the other hand, if carbon sequestration and storage decline, the forest becomes a **carbon source**. Natural disturbances like hurricanes, insects, and wildfire contribute to carbon emissions from forests. Deforestation – the conversion of woodlands to another land use – is especially harmful for the carbon balance of a region. While a warming climate may actually increase forest growth in some regions and improve its ability to capture and store carbon, it is equally likely that extreme weather would undo any such incremental gains in carbon capacity due to increased mortality though extreme climate-induced events described in earlier chapters.

Canada's managed forests and forest products remain a net carbon sink, though the strength of that sink has decreased since 1990. This is according to the National Inventory of Greenhouse Gases. The decrease is due to intensified forest management that has reduced landscape-level carbon stocks, especially as a result of insect outbreaks and management interactions in western Canada. The increasing severity of wildfires – especially in drier regions – threaten the country's forest sinks. Despite this, the Paris Agreement has endorsed forests as a major potential contributor to the sequestration of carbon and a mitigative measure against climate change. Data from the national inventory of GHGs and provincial forest inventory data show that Nova Scotia forests remain a carbon sink. **With proper understanding and management, Nova Scotia's woodlands can play a role in our local, national, and global efforts to fight climate change.**

Objectives in woodland carbon capture and storage

Global climate change is just that - global. It affects everyone on earth, and everyone can do their part to mitigate their own contribution to the emissions of GHGs. However, individuals with woodlands have an added tool in their toolbox in that best management practices can be implemented to improve the carbon outcomes of one's woodland to help fight climate change. In other words, every Nova Scotian can reduce their own emissions, but woodland owners have the added ability to *remove* CO_2 from the atmosphere.



Old growth forest showing carbon storage in living biomass and dead organic matter (photo credit: Peter Duinker).

Many activities in woodland management can help capture and store carbon. A first useful way to look at it is through the lens of ecological forestry and the triad. Partial harvests and uneven-aged management of forests in ecological forestry – called the ecological matrix – leaves more carbon stored on the landscape in both living forest biomass and dead organic matter, including soils. This approach still allows for some timber harvest but restricts the amount of wood that can be removed from the forest.

Another approach could fit more with the **high production** zone of the triad and involves much more investment in silviculture and rapid forest growth. Tree planting of high-quality or even genetically improved seedlings and pre-commercial thinning to reduce competition and ensure full stocking can lead to big increases in forest growth that correspond to increases in stored carbon. If priority is placed on long-lived wood products that store carbon for decades – sometimes longer than it takes to recapture that carbon in the forest – there can be benefits for climate-change mitigation. However, this approach does come without trade-offs and does not provide the benefits for biodiversity that the former one does. Care must also be taken to ensure there are no long-term declines in soil carbon, which is a large and important pool of forest carbon. It is critical that short-term gains in carbon and production do not have long-term carbon consequences for soils.

Logs stacked roadside at an irregular shelterwood trial in Antigonish County (photo credit: James Steenberg).

Conservation – the third zone of the triad – is always an available tool for woodland owners. While this translates into no harvesting of wood products, in many forest types it ensures that the carbon stored in the forest remains stored and of course provides ample benefits for biodiversity. Conservation is an especially valuable tool for carbon management in areas where the threat of deforestation and development is high or where old-growth forest is present.

There are a few other important considerations outside of these three broad approaches to woodland carbon management. If your woodland is ecologically degraded due to past management or disturbance, **ecological restoration** activities like tree planting or controlling invasive species can help bolster the carbon benefits of the land. **Afforestation**, such as converting marginal farmland back to forests, provides especially large carbon benefits. On the other side of that coin, avoiding **deforestation** and the conversion of woodlands for development will help to prevent carbon emissions from the land.

Effects of Silviculture on Carbon Stocks

Forest management and different silvicultural treatments provide a range of carbon opportunities for the woodland owner. **Tending** treatments like pre-commercial thinning, crop-tree release, and commercial thinning help to increase forest growth and carbon sequestration in residual trees. **Pre-commercial thinning** especially provides both carbon and fibre benefits while also providing opportunities to direct species composition, for example to climate-adapted species.

Uneven-aged silviculture will keep more carbon on the landbase, both in the retained trees and dead organic matter. **Shelterwoods** – both traditional shelterwoods and especially irregular shelterwoods – meet these objectives while also being proven tools in Nova Scotia for creating natural regeneration of LIT species and a well-stocked healthy forest. It might go without saying, but natural regeneration is a low-emissions method of regrowing your woodland.

Selection management checks a few boxes for sustainable forestry, from fostering resilient, multi-aged stands to focusing on managing for high quality logs. While maintaining good stores of carbon on the landscape, it can also translate to better carbon storage in long-lived products. For example, selection management in tolerant hardwoods is a silvicultural approach that mimics the natural disturbance regime of these forests to help maintain biodiversity while promoting high-quality products. The carbon in hardwood products like flooring may remain trapped in the wood for a century or more.

All of these uneven-aged silviculture prescriptions also help to conserve soil carbon by keeping temperatures lower under the remaining canopies, which in turn assists in reducing soil decomposition and keeping dead organic matter on site, which feeds the soil carbon pool. An important practice to further conserve soil carbon is to avoid soil disturbance – especially of the mineral soil – during harvest operations.

A student samples soil carbon.

Simple even-aged management techniques like overstorey removals (that is, clear-cuts) tend not to provide the best carbon outcomes, both in terms of carbon sequestration and storage in the forest and carbon storage in long-lived, high-quality wood products. However, they can be a tool in the carbon toolbox, for example, when combined with intensive silviculture in a high-production model because of the big gains in carbon sequestration and yields of long-lived wood products.

At the end of the day, it important to remember that not all silvicultural treatments are suitable for a given forest ecosystem type or stand conditions. For example, balsam fir is a short-lived and shallow-rooted species in Nova Scotia and a selection treatment would not be suitable and potentially lead to carbon emissions as the trees decline or are blown down. The species is also not well adapted to the warming climate. Appropriate silviculture and carbon objectives should be considered side by side.

Like so many aspects of forestry, long-term vision is needed when considering carbon goals and silviculture for your woodlands. Any combination of these silviculture approaches can lead to a woodland being a long-term carbon sink if sustainable harvest levels are also considered. A goal in planning for your woodlands should also be big picture and long term. In addition to carbon-smart and appropriate silviculture for a given operation, long-term forest management plans that integrate carbon (like those strategies discussed in section 5.2) into other management objectives will help improve the carbon storage and sequestration of your entire woodland, its surrounding forest landscape, and all of Nova Scotia.

How does forest carbon capture and storage work in the economy?

While carbon is becoming a big part of the traditional forest economy, it is also leading to the creation of entirely new carbon economies. Woodland owners may have opportunities to participate in **carbon markets** where they can sell the service of carbon sequestered and stored in their woodlands. Carbon markets enable the trading of **carbon credits**. A carbon credit is one tonne of CO_2 and in carbon markets the credits are traded between, or purchased by, companies that emit GHGs. Carbon credits might be created by things that reduce emissions like the capture of methane at landfills, but in forests the credits are created by avoiding GHG emissions through improved forest management, afforestation, or conservation.

Two carbon markets are currently in use: the **compliance market** and the **voluntary market**. In regulatory compliance markets, emission reduction targets are set by a regulatory body. For example, a provincial or state government may have a regulated cap-and-trade market. In a cap-and-trade market, specific industries are required to keep their emissions below a set cap. If a company cannot stay below its cap, it can trade its emissions with other emitters that still have room below their own caps. Often in cap-and-trade markets, emitters can also purchase carbon offset credits to help them stay below their caps. The credits are generated from projects outside of the cap-and-trade market that are proven to reduce carbon emissions.

Of course, an example of interest here is carbon credits from forests. These forest carbon credits may be generated by improved forest management that increases carbon storage and sequestration. They may be from forests that are conserved from deforestation. Or they may be new afforestation or even ecosystem restoration projects. The landowner – and a third party that sets up the project – are paid for their proven incremental improvements in carbon sequestration and storage on their woodlands. Currently, there are little-to-no opportunities for woodland owners in Nova Scotia to sell their carbon credits in a regulatory market. However, at the time this learning module was created, the Government of Canada was working to develop a national protocol for forest carbon credits that could be sold across the country.

In contrast to these regulatory markets are voluntary carbon markets. In voluntary markets, emitters can purchase offset credits from projects that aim to reduce or remove GHGs from the atmosphere. The key difference from compliance markets is that the companies that are reducing their emissions by purchasing carbon credits are doing so on a voluntary basis, not a legal one. This also means that the price of carbon is not set by a government but is subject to supply and demand.

Voluntary markets can be cross-boundary and international. They often are organized around registries or organizations that adopt internationally accepted standards and protocols for how carbon credits can be generated, measured, and sold. One prominent example is the American Carbon Registry. Newer models of voluntary carbon markets are emerging, such as deferral models where a company offers a landowner carbon credits to delay the harvest by one year to sequester more carbon. Woodland owners in the province can currently sell their carbon credits on voluntary markets, but that is entirely dependent on an available buyer.

Some problems exist with carbon market standards and models more generally, including the length of project terms and minimum woodland size. Carbon offset programs usually have minimum timeframes of 10 to 100 years, which is far longer than many woodland owners are comfortable with. Carbon markets can also be difficult to access for woodland owners, as there is a considerable cost associated with establishing, verifying, and monitoring a forest project, which is especially challenging for smaller woodlands.

Outside of carbon markets, there are emerging opportunities for woodland owners in the growing **forest bioeconomy**. New research and technology are leading to the creation of new forest-based products from wood and waste that have lower carbon emissions than their typical alternatives. These range from liquid fuels that can substitute for diesel to bioplastics in place of petroleum-based plastics to mass timber that can replace concrete and steel in building construction. Keeping apprised of new forest carbon opportunities is certainly a smart addition to managing your woodland carbon.

Quiz 5

1 What are the two main pools of forest carbon?

a. Living biomass and living organic matter

b. Living biomass and dead organic matter

c. Storage and sequestration

d. Sink and source

2 A forest is a carbon source if there are more CO_2 emissions removed from the atmosphere than emitted to it. ☐ **True** ☐ **False**

3 What kind of forest productivity includes carbon sequestered from photosynthesis and carbon emissions from both cellular respiration and decomposition of deadwood in the forest and forest products?

a. Gross primary productivity

b. Net primary productivity

c. Net ecosystem productivity

d. Net biome productivity

4 Name three discussed strategies for managing woodland carbon.

a. Afforestation, deforestation, and restoration

b. Improved forest management, agriculture, and conservation

c. Afforestation, restoration, and improved forest management

5 Pre-commercial thinning is a silvicultural tool for stand tending that can improve carbon sequestration and storage. ☐ **True** ☐ **False**

6 Forest soils are a very large pool of carbon. ☐ **True** ☐ **False**

7 Selection management is a silviculture system that can potentially increase long-term carbon stocks on a woodland compared to simple even-aged management. ☐ **True** ☐ **False**

8. What are the two main kinds of carbon markets were carbon offset credits can be sold?

a. Compliance and voluntary

b. Voluntary and required

c. Compliance and non-compliance

d. Carbon and nitrogen

Summary and Conclusions

Across the world the climate is changing, and Nova Scotia is no exception. Woodland owners can expect a warmer, wetter future with more extremes in weather. More importantly, woodland owners should build their understanding of climate, climate change, and its impacts on forests in order to adapt their management and even to fight climate change with their forests. This home study module provided some basic information, tools, and approaches to start woodland owners on this journey.

While all may be familiar with the weather and know how drastically it can change on a daily and even hourly basis in this province, it is climate that describes the longer-term trends in weather in Nova Scotia. At its most basic, climate is driven by energy from the sun. Earth's atmosphere naturally contains many gases called GHGs that capture that solar energy and keep it from going back out to space just long enough to make our climate tolerable for life.

However, since industrialization humans have been increasing the amount of these greenhouse gases in the atmosphere, which is warming our climate and causing a host of other problems under the umbrella of climate change. Climate change is happening mainly due to the burning of fossil fuels and resulting release of the GHG CO_2 into the atmosphere, though there are other types of GHGs and other causes of climate change (deforestation, for example).

Here in Atlantic Canada and Nova Scotia in particular, there will likely be average annual temperature increases of as much as 3-4º C. There will also likely be increases in precipitation by several hundred mm, with more precipitation falling as rain, not snow, and more intense rainfall events. This warming and changes in precipitation have a direct effect on forests, including drought (even with increased rainfall on average), heat stress, some increases in growth for a few tree species, and potentially the long-term shifting of our tree species' ranges. The Acadian Forest Region is a transitional region and has many colder-climate boreal species like balsam fir and white birch that may suffer more under climate change and shift their ranges to cooler places. It also contains warmer-climate temperate species like red maple and white pine that may actually benefit from climate change and become more abundant over the long term.

There are other effects of climate change on forests as well. The increased amount of energy in our atmosphere and oceans and more climatic extremes are causing more frequent and severe natural disturbances. Natural disturbances like windstorms, hurricanes, wildfire, insects, and pathogens have major impacts on our forests but are an important driver of their natural ecology. However, we are seeing them more often and they are more intense that what was historically the case – natural disturbances are becoming unnatural and having negative consequences for Nova Scotia's forests. Post-tropical storm

Fiona and its devasting impacts will still be fresh on people's minds. Under climate change, we can expect more windstorm disturbance and more intense hurricanes. Despite a wetter future, the risk of wildfire is also increasing in the province. Warmer conditions will also generate conditions favourable for many forest insects and pathogens, including new invasive ones like the hemlock woolly adelgid. Importantly, more disturbances typically beget more disturbances and there are interacting, cumulative impacts to be expected, like wildfire starting in blowdown from hurricanes.

Fortunately, there is a host of tools in the woodland management toolbox that can help landowners adapt to climate change. A useful starting point is to understand the vulnerability of the different forest ecosystems to a changing climate. Vulnerability includes exposure, which is the changing climate, weather, and disturbances that woodlands will actually face. However, vulnerability also includes sensitivity. Different forest ecosystems have varying levels of sensitivity or likelihood of experiencing adverse impacts. A stand of balsam fir is more sensitive to warming than a neighbouring stand of white pine because of the different climates they have evolved in. An even-aged stand is likely more sensitive to wind disturbance than an uneven-aged stand. The third dimension of vulnerability is adaptive capacity, which is the ability of both a woodland and a woodland owner to cope with and combat the impacts of climate change. A woodland owner carrying a strong foundational knowledge of climate change and forests has greater adaptive capacity and lower vulnerability.

Tools for adapting woodlands to climate change include many of the approaches to ecological forestry and the triad recently adopted in Nova Scotia. The silvicultural treatments in Nova Scotia's Silvicultural Guide for the Ecological Matrix focus on the use of uneven-aged management that create stands with diverse structure and composition, which will be more climate-resilient. The high-production forestry zone of the triad provides some other management opportunities for adaptation, like shorter harvest intervals that give managers a quick reaction time to accommodate shifts in climate and natural disturbances. Moreover, wherever tree planting is occurring there can be assisted migration, which means moving seed or species from one area to another to ensure future forests are adapted to future climates. Stand-tending silviculture like pre-commercial thinning can also help to build climate resilience by favouring naturally occurring, climate-adapted species while also increasing stand growth.

Lastly, woodland owners in Nova Scotia can contribute to the global fight against climate change and the reduction of GHGs in the atmosphere with their forests. In a process known as the carbon cycle, forests sequester CO_2 from the atmosphere as they grow and store it for long periods of time. Forest carbon is stored in living trees, but also in soils and dead organic matter like snags or woody material on the forest floor. Improved forest management can help to

remove more carbon from the atmosphere and make forests into powerful carbon sinks, thereby mitigating global climate change. This might happen through conservation, ecological restoration, or ecological forestry treatments that lead to more carbon stored in the forest, or through the better production of long-lived wood products and a forest bioeconomy that reduce the need for alternative products that rely heavily on fossil fuels. Afforestation and avoiding deforestation are particularly important for boosting forest carbon. As global markets evolve and adapt to climate change too, there may be economic opportunities for landowners to sell the carbon stored in their woodlands as carbon offset credits. Global climate change is just that – global. It affects everyone on earth, and everyone can do their part to mitigate their own contribution to the emissions of GHGs. However, woodland owners have an added advantage and can use their forests to fight climate change.

Glossary

Abiotic: Physical objects, but not biological. Devoid of life. E.g., rocks, wind.

Atmosphere: The envelope of gases that surround a planet. Earth's atmosphere is composed of 78% nitrogen, 21% oxygen, and one percent other gases. Carbon dioxide's concentration in the atmosphere is just over 0.04%.

Biotic: Living things or effects resulting from living things.

Climate: The long-term trend of weather patterns within a region or location.

Climate Change: The long-term shift in temperature, precipitation, and wind patterns across the globe or in a region.

Climate Normals: The 30-year average of a given climate variable for a given time of year. Usually provided for specific months, these measurements can also span seasons.

Climatic Range/Climate Envelope: This describes the influence of climatic (temperature and precipitation) variables on the occurrence of species.

Chronic: Otherwise termed 'persistent pests', these organisms present an ongoing problem for host species throughout a season or year.

Convective Storm Cells: Formed during thunderstorms, these units of air-mass up and down drafts that are fed by the difference in density of hot and cold air.

Daily Minimum/Maximum: The average daily minimum and maximum temperatures of a given month or season over a 30-year period.

Disturbance Agents: The forces of nature that damage or kill significant numbers of trees, some being host-specific and some not. In Nova Scotia, this includes insects, pathogens, fire, and wind.

Disturbance Regimes: The average spatial extent and frequency of a given natural disturbance over a period of time.

Evapotranspiration: The total water loss of a terrestrial ecosystem to the atmosphere. In forests, this includes water vapour from evaporation from surfaces in the ecosystem and from transpiration from leaves.

Extra-tropical Cyclones: A type of storm formed in mid-high latitudes, these usually come to Nova Scotia in the form of snowstorms, rainstorms, and Nor'easters.

Extreme Minimum/ Extreme Maximum: The coldest and hottest temperature recorded in a given timeframe over a 30-year span.

Forest Pathogens: Living organisms that inflict diseases on a host; in Nova Scotia, most forest pathogens are fungi.

Freeze-thaw Cycles: The freezing and thawing of water contents in forest soils. This can cause soil erosion as water seeps into soil, freezes into ice, and expands again when temperatures warm, causing cracks or pores in soil to expand.

General Circulation Model: A mainstay in climate modelling, this type of model employs mathematical simulations of the circulation of both the atmosphere and oceans of the world. This type of model is used to predict future climate changes and weather forecasting.

Global Warming: The increase in the overall temperature of the earth's atmosphere because of greenhouse gases.

Greenhouse Effect: The trapping of heat resulting from infrared radiation absorption by greenhouse gases, thereby heating the atmosphere.

Greenhouse Gas: A group of gases that strongly absorb infrared radiation, powering the greenhouse effect. These gases include carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), water (H_2O), and nitrous oxides (N_2O).

Heat Stress: When air and soil temperatures exceed a particular threshold, transpiration rates cannot keep pace with rising temperatures to sufficiently cool the tree, causing leaf and stem damage.

Hurricanes: A tropical storm with sustained winds at or exceeding ~120 km/h.

IPCC: The Intergovernmental Panel on Climate Change: an international governing body of the United Nations, this organization advances scientific knowledge of human-induced climate change.

Irruptive: Native pest species that experience booms in populations, usually very sudden.

LIT: Long-lived intermediate or tolerant species that are well or somewhat well adapted to growing under canopy shade, such as red spruce, eastern hemlock, white pine, white spruce (forest), sugar maple, yellow birch, red oak, red maple and white ash.

Ozone Layer: Within the stratosphere, this intermediary layer acts as a protective layer for all life on earth. This layer blocks dangerous UV radiation and can be negatively affected by the emissions of chlorofluorocarbons (CFCs).

Plant Respiration: The process of using sugar and oxygen to repair tissue and develop new growth in plants. This expels carbon dioxide and water vapour.

Precipitation: Any product of the condensation of atmospheric water vapour that falls to the surface of the earth.

Provenance Trials: A type of experiment that allows researchers to understand how tree species can adapt to different environments.

Return Interval: Given in year estimates, this quantity really projects the probability of equivalent or exceeding event happening in any one year. Thus, a return interval of 174 years has a 0.6% chance of occurring each year (1 year divided by 174-year return interval).

Soil Moisture: The water content of unsaturated soil. Includes water vapour.

Solar Radiation: All electromagnetic radiation emitted by the sun, including visible, infrared, gamma, and ultraviolet radiation.

Stomata: Small openings or slits in leaves and stems which facilitate and control the rate of gas exchange between the atmosphere and a plant.

Stratosphere: The layer immediately above the troposphere. One may travel through this layer of the atmosphere during an air flight.

Transpiration: The expelling of water vapour from plant stomata. This process cools the individual plant.

Tropical Cyclone: A type of storm formed in the tropics that travels latitudinally to the pole.

Troposphere: The lowest layer of Earth's atmosphere. This layer is where weather occurs and most cloud types are limited to this layer.

Thermal Expansion: The expansion of an object, in this case ocean water, in response to an increase in temperatures.

Radiative Forcing: A measure of the transfer of energy from the sun to earth's atmosphere, this quantity (watts/m^2) accounts for energy trapped by greenhouse gases in the atmosphere.

Representative Concentration Pathway: a GHG concentration trajectory that includes the estimation of radiative forcing; IPCC uses four pathways as inputs to GCMs and other climate models when estimating temperature and precipitation pattern shifts.

Winter Desiccation: Common winter injury that occurs when water expelled by the leaves exceeds the water picked up by the roots. Mostly occurs in evergreens.

Xylem: The tissue of plants that conducts water and dissolved nutrients through the woody portion of a plant, usually in the direction of roots to leaves.

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Notes

Notes

Answers to Quizzes

Quiz 1	Quiz 2	Quiz 3	Quiz 4	Quiz 5
1......**B**	1......**A**	1......**C**	1......**A**	1......**B**
2......**D**	2......**False**	2......**A**	2......**True**	2......**False**
3......**D**	3......**A**	3......**B**	3......**A**	3......**B**
4......**B**	4......**False**	4......**False**	4......**True**	4......**C**
5......**False**	5......**C**	5......**True**	5......**False**	5......**True**
6......**True**	6......**True**	6......**True**	6......**A, B, C, D**	6......**True**
7......**False**	7......**A**	7......**True**	7......**A**	7......**True**
8......**False**	8......**True**	8......**True**	8......**True**	8......**A**
9......**False**				

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