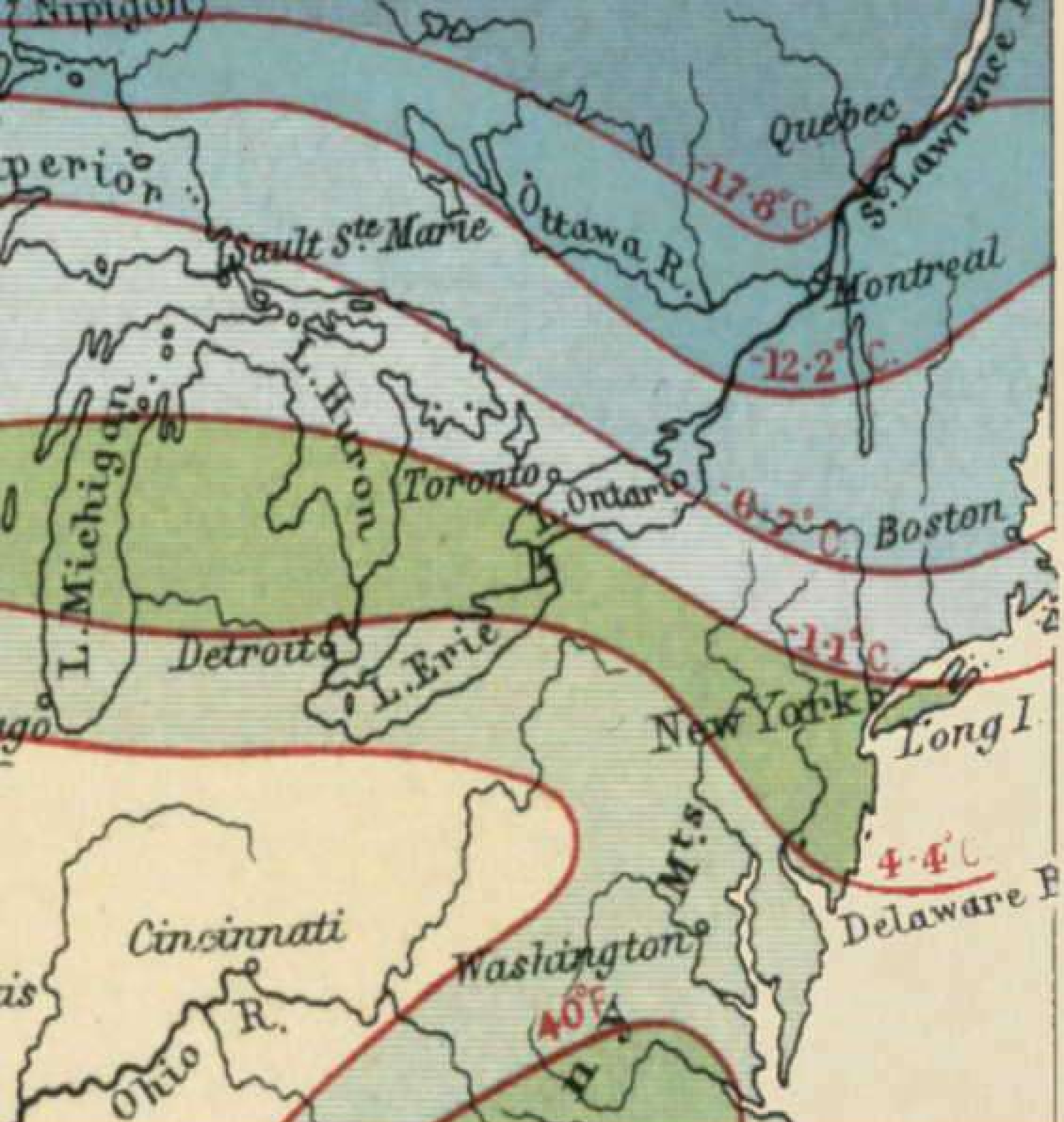

Climate Adaptations in the Northeast's Forest Products Supply Chain

A Vulnerability Assessment of the Primary Forest Products Sector

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE
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NORTHEAST FORESTS, LLC

Climate Adaptations in the Northeast's Forest Products Supply Chain: A Vulnerability Assessment for the Primary Forest Products Sector

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Abstract

Changes in the climate are having a significant influence on the Northeast's forest products supply chain. Average December and January temperatures are over four degrees (Fahrenheit) warmer than they were in the 1980s in much of the Northeast. June receives a full inch more of precipitation, on average, than in the past and the month of October receives 1.5 inches more precipitation. These changes increase the risks in the forest products supply chain. This study documents that landowners, loggers and mills have adapted to these changes in ways that help minimize this risk and continue operations. Harvest scheduling has become more complicated for landowners, creating a ripple effect in the supply chain. Best management practices (BMPs) for water quality became widespread in the region even as changes in the climate were occurring. The combination of more challenging conditions and widespread BMP compliance causes multiple stresses in the supply chain. Road maintenance and improvements are necessary to accommodate both demands for wood and climate challenges. Timber harvesting systems have been adopted and adapted in response to climate impacts and threats. Mills have taken creative steps to procure supply during periods when unsuitable harvesting conditions limit the supply of wood. The spread of forest pests and invasive species has altered harvesting plans, opportunities and forest worker safety throughout the region. Climate-related government policies have influenced markets for low-grade wood and are creating uncertainty about the viability of some aspects of the forest products supply chain.

FOREWORD

In order for readers to contextualize the effects of climate change and resulting adaptations, some sections of the report describe business as usual practices in the forest products supply chain and then describe climate adaptations to these practices. These climate adaptations have occurred over time and in the context of the everyday pursuit of supply, operations and forest management goals.

INTRODUCTION

Throughout the Northeast, warmer and wetter conditions are affecting the ability to get wood from the forest to markets. In response, workers are making small but important adjustments. Perhaps loggers are working more when frozen conditions allow the least impacts to soils and water. Mill owners might key into those times when loggers are more active, stockpiling logs and preparing for down times. Foresters and landowners may adjust harvest plans to prevent impacts of proliferating invasive species.

All of these can be considered adaptations to climate change, although individuals will seldom classify their actions as such. Nevertheless, each adjustment, however subtle, is a response to risk perceived from changing climatic conditions, often in combination with other forces.

The forest products supply chain in the Northeast has identified risks associated with climate change and taken adaptive actions. The individual responses of distinct entities to specific concerns at a micro-level can collectively be labeled as climate responses. Trends that emerge from the entirety of these actions clearly point to climate-influenced risks.

Individuals and businesses can logically be expected to instead alter their structures, methods and business models in ways that minimize their risk to climate change. While collective actions may be employed to alter the root causes of climate change, individual actions in the form of adaptions present the most immediate form of relief from its consequences.

Risk and Adaptation

Changes in seasonal weather patterns over time have spurred adaptations in the Northeast's forest products supply chain. These Adaptations are responses to risk.

Chapter 28 of the Fourth National Climate Assessment (USGCRP, 2018) states:

> *"Adaptation refers to actions taken at the individual, local, regional, and national levels to reduce risks from even today's changed climate conditions and to prepare for impacts from additional changes projected for the future........Adaptation is a form of risk*

management.......Individuals, business entities, governments, and civil society as a whole can take adaptation actions at many different scales. Some of these are changes to business operations, adjustments to natural and cultural resource management strategies, targeted capital investments across diverse sectors, and changes to land use and other policies. Adaptation actions can yield beneficial short-term and/or longer-term outcomes in excess of their costs, based on economic returns, ecological benefits, and broader concepts of social welfare and security. Moreover, many strategies can provide multiple benefits, resulting in long-term cost savings."

The forest products supply chain in the Northeast has recognized risks associated with climate change and taken adaptive actions consistent with the US Global Research Program (USGSCRP) description.

Identification of climate adaptations by individuals and distinct segments within the forest products sector often requires broad, probing discussions that include all facets of change over time. Climate change is seldom brought up as a singular topic. Discussion of specific results of climate change, such as a shorter winter season or higher soil moisture in summer months, makes it easier to isolate and describe adaptations and climate-smart practices.

Asking interviewees and focus group participants to name specific vulnerabilities to the work that they do was not productive. At best this prompted a few general responses (e.g. markets, tariffs, labor, cost, weather). Asking how and if participants responded to various climate-influenced changes over time was effective in prompting insight. Subsequent sections of this report detail and expand on these responses.

The Forest Products Supply Chain

The primary forest products supply chain can be succinctly described in three links: forests, logging and wood-using mills. Each of these links has a multitude of specific risks and concerns it addresses in its operations. The climate-related risk in each link of a functioning supply chain, however, is readily defined in general terms:

Supply Chain Link	Risk
Forests	Ability to schedule and complete timber harvests following acceptable standards
Logging	Ability to produce enough to be financially viable

Mills	Ability to procure sufficient volume and quality of wood on a timely basis

The specifics of climate risks and adaptations for each of these links in the Northeast's forest products supply chain are described in this report. The information for these descriptions was collected in interviews and focus group discussions with participants in this supply chain. This group includes landowners, foresters, loggers and mill owners and operators. Those interviewed were a cross-section of the people and roles found within each. Among them are both public and private sector lands managers, small and large landowners, loggers using each of the three main ground-based harvesting systems in the Northeast, and a wide range of mill types (hardwood lumber, softwood lumber, paper, electrical utility).

The primary risk to each link in the supply chain has multiple contributing factors. Many of these contributing factors are influenced by climate change.

Anything that impacts the ability to schedule and complete timber harvests in an acceptable manner, the opportunity to harvest enough wood to be financially viable or to procure enough wood to meet supply needs will contribute to the risk of adverse outcomes. Markets for wood products are a primary driver for each link in the chain. While changes in the climate have little direct relation to markets for wood products, changes in climate-related policies at the federal, state and local levels sometimes do.

Ground conditions – wet, frozen, dry or otherwise - dictate the possibilities for harvesting timber, maintaining logging production and ultimately creating the timber supply relied upon by mills. Ground conditions are heavily influenced by seasonal weather patterns. Changes in these patterns over time are notable drivers of the climate adaptations detailed in subsequent sections of this report.

Further factors including access, trucking, logger availability, landowner plans and silvicultural considerations are risk contributor that are all also subject to climate influence. Each of these topics is explored in discussing the climate adaptations that were documented in this study.

Approach

The information included in this report arises from discussions with individuals and groups of forest products professionals in the Northeast. A total of 76 people provided input in individual interviews or one of four focus group sessions.

Each meeting began with a summary of seasonal changes in temperature and precipitation in the Northeast as a baseline for discussion. Climate information was based on data from the National Oceanic and Atmospheric Administration (NOAA). This was followed by a discussion of climate-impact related topics including:

- Impacts on forest management and harvest scheduling;
- Impacts on logging and logging equipment;
- Impacts on wood procurement by mills;
- Best management practices for water quality;
- Forest pests, diseases and invasive species; and
- Policy impacts.

This report follows a similar format, beginning with a discussion of monthly and seasonal temperature and precipitation trends in the region. Then, interview and focus group meetings are summarized for each of the climate related topics discussed. Finally, this report summarizes climate adaptations observed throughout the Northeast's forest products industry.

Two case studies are included in the appendix to this report, along with monthly county level average precipitation and temperature comparisons between the 1980s and 2010s.

Climate Change & The Supply Chain

The Northeast has become warmer and wetter during key parts of the year for the forest products industry. These changes impact the entire forest products supply chain. Changes in seasonal weather patterns, including increasing temperatures and more rain or snow have become part of the work environment. A close look at climate records reveals that the seasons have changed considerably in the past few decades.

Comparing average monthly weather conditions in the 1980s to the 2010s is informative. The National Oceanic and Atmospheric Administration (NOAA) compiles annual climate records for locations across the United States. NOAA data for average temperatures and precipitation by month in each Northeastern state and county, by decade, were examined.

Comparing average monthly weather conditions for the period from 2010-2019, with the 1980s reveals warmer temperatures in the winter logging season, along with increasing precipitation, mainly in the summer and fall. In many locations winter precipitations is rain instead of snow.

In the Northern Forest states of Maine, New Hampshire, New York and Vermont, the biggest temperature changes from a logging standpoint are in December and January, with average monthly temperatures in the last decade that are at least 3.5 degrees warmer than the 1980s (here and throughout, all temperatures are measured in degrees Fahrenheit).

The most notable increases in precipitation take place in June, with average rainfall increasing from 4.1 to 5.1 inches, and in October, where average rainfall of 3.5 inches in the 1980s has increased by 1.5 inches to 5 inches over the last decade.

Southern New England and Pennsylvania exhibit similar changes over time and so were grouped together. In these states, average temperatures are 3 degrees higher in January and 4.5 degrees warmer in December, when comparing the 1980s to recent years.

September, October, and December are all wetter in the southern portion of this region. Each of these months now brings more than four inches of precipitation—at least an inch more than what was seen in the 1980s.

Summaries of monthly temperature and precipitation changes for both areas are shown in Table 1.

Climate Trends by State

Over the past century, temperatures have increased 2-3 degrees in the Northeastern states including Connecticut, Maine, Massachusetts, New Hampshire, New York, Pennsylvania, Rhode Island and Vermont. These states have also seen increased rain and snow, particularly in the winter and spring, as well as more frequent extreme rain and snow events, defined by NOAA as storms bringing more than 2 inches of precipitation. Other trends include more warm nights (minimum temperatures not falling below 70 degrees) and fewer very cold nights (with minimum temperatures below 0 degrees).

Notable trends include:

- In Connecticut, average annual precipitation has generally been above the long-term average every year since the 1970s;
- In Maine, the decade from 2004-2014 saw a record number of extreme precipitation events—twice the long-term average;
- In Massachusetts, the number of very cold nights has been below average since the early 1990s.
- In New Hampshire, winter warming has been greater than any other season, with an increase of about 4 degrees since 1900;
- In New York, temperatures in the 2000s have been higher than any other historical period, with warming concentrated in winter and spring;
- In Pennsylvania, warming has also been concentrated in winter and spring. There has been a decrease in the number of very cold nights;
- Rhode Island has experienced a marked increase in the number of hot days with temperatures above 90 degrees. The number of hot days has been above the long-term average since the 1990s; and
- In Vermont, the growing season has lengthened by an average of 4 days each decade for the past four decades, associated with warmer temperatures in both winter and summer, and more frost-free days.

State-level data tends to show a set of average conditions that isn't truly representative of smaller regions within the state. No one will ever confuse winter in New York's Adirondack Mountains with the conditions experienced on Long Island, or those in Maine's Aroostook County with the Portland area. Many observers believe that the fringes of the colder areas have experienced the most significant changes, where the difference of a few degrees can really alter winter snow cover and moisture patterns.

A state-by-state breakdown of monthly changes between the 1980s and the past decade is shown in Table 2.

Supply-chain Impacts

Logging chance is a term used to describe the site characteristics and related conditions for an individual harvesting job, including not only weather, but also the type of harvest, merchantable volume, tree size, topography and ground conditions. Clearly, climate and the time of year play important roles in determining the logging chance on any given site.

Changes in the logging chance are increasing harvesting costs in two ways. First, added techniques and equipment are needed for any given job. On top of this, compressed logging seasons make fewer days available for loggers to turn a profit because fixed costs must be spread over fewer productive days. With fewer opportunities to produce among their suppliers, mills need to look to more suppliers over a greater supply area to meet their needs. Ultimately mills will have to increase pulpwood prices or suffer the consequences of a loss of the supply.

The winter logging season is the most productive portion of the year for many businesses, but recent trends curtail production. Warmer temperatures in December and January can make it difficult to access and operate in forest stands that require snow cover, frozen ground and winter roads.

Many sites are only accessible or operable during winter conditions. Here, logging relies on frozen ground to access sites without damage to roads, wetlands, streams and water bodies. These winter conditions sometimes begin in December, though it may be January before ideal conditions are realized. March 15th is a hoped-for minimum season length and in good years it extends even later. Early warm temperatures, melting snow and direct sunlight combine to put an end to the season.

Changes in precipitation are affecting harvesting scheduling, logging productivity and the supply of wood to mills. Most states in the Northeast are seeing more summer rain, particularly June and August. Increased summer rainfall causes forest soils to become saturated, with excess rain water pooling up and running off. This excess water will often interfere with harvesting jobs that are underway and can limit access to some harvesting sites. Frequent starts and stops make it hard to establish a rhythm of steady production. There has been industry-wide commitment to best management practices for water quality over the past two decades. Following these safeguards sometimes means that sporadic working conditions make it difficult to stick to a schedule and keep both mills and landowners happy.

Increased rainfall in October comes on the heels of the warmer Septembers that have come to be recognized as the most productive part of the summer in parts of the region. Forests now get 1 to 2 inches more precipitation in October than they have in the past, even as temperatures are cooling, the leaves are falling and both transpiration and evaporation are slowing dramatically. No matter that Novembers have less rainfall and snow than in past years. If ground conditions become fully saturated in October they can remain saturated in November, even without much additional precipitation. The inevitable result is ponding in the woods and swollen runoffs and watercourses. A fall mud season appears and logging production drops.

Frozen Winter Conditions

Winter has traditionally been a time of productive timber harvesting conditions in the Northeast. Timber harvests were scheduled in winter for accessibility and protection of sites with poorer drainage. In cold weather, the ground is frozen to accommodate logging equipment and the equipment itself is subject to less wear with snow cover. Mills take advantage of winter harvesting to replenish their supply of wood in anticipation of reduced supply flow in the spring mud season.

In many parts of the Northeast, winter no longer follows the same pattern as it did in the past. Some of the people interviewed report that historical winter conditions no longer occur, do not occur every year or occur for much shorter time frames. County-level NOAA temperature data was examined to help quantify this tend and identify it spatially.

It is generally agreed that freezing winter conditions in January are a requirement for a full or nearly full traditional winter timber harvesting season. Temperatures well below freezing – in the single digits – are required to freeze trails and roads and protect the ground. After consulting with knowledgeable forest workers and the Northeast Climate Hub, an average monthly temperature of 20 degrees was chosen as the maximum temperature that should still be considered for providing acceptable winter operations.

A comparison of Northeast counties having frozen winter logging conditions in most years is shown in Figure 1, using a 20-degree maximum average temperature as the criteria. Today, 30 fewer counties in New York and New England have frozen winter logging conditions than did in the 1980s.

Frozen winter logging conditions are present in December in some northeastern locations. Often this come in the form of an uninterrupted week or more of freezing conditions that provide an opportunity to freeze access roads and landing sites. This December logging opportunity has disappeared or been sufficiently limited in some locations. A comparison of Northeastern counties with freezing December conditions was made, using a maximum average monthly temperature of 25 degrees as the criteria. Twenty-five degrees is used, rather than the colder 20 degrees used for January, because December is a transitional month into winter conditions. This comparison is shown in Figure 2. A total of 38 counties meet the average monthly temperature threshold of 25 degrees (F) or less in the 2010s than in the 1980s.

The county-level is a bit coarse for this comparison but represents the best data available. There is considerable local variation with the region and the counties themselves, much of it dependent on elevation.

Trends and Predictability

The NOAA temperature and precipitation numbers bear witness to changes in logging conditions over time, but there is more to the story than just warmer and wetter conditions. The general trends have not followed a straightforward path to present circumstances. Weather in the Northeast has become more difficult for the forest products supply chain to rely on and make plans around.

Vermont records provide a good example. While it's true that the average monthly temperature for January has been 4 degrees warmer over the past ten years than it was in the 1980s, the fluctuation in average temperature over that time period has been much greater. In some years January has been over ten degrees warmer than historical averages. In other years, this month has been eight to ten degrees colder.

Similar variability is also seen in snow and rainfall in Vermont. Records show that October rainfall has been up to 6 inches greater than historical averages in some years and as much as 2.5 inches less in others.

Wide variations in temperature and precipitation, in practical terms, mean a lack of predictability and greater risk. Lack of predictable seasonal weather conditions make it more difficult to schedule timber harvests and plan operations. Selection of logging equipment becomes more challenging.

Mills find their inventory control less predictable. The already difficult jobs of managing timberlands, logging and procuring wood inventories become more challenging. Direct impacts and adaptations in the supply chain are discussed in the sections that follow.

Table 1. Differences in monthly average temperatures and precipitations between the 1980s and 2010s.

Northern Forest States (ME, NH, NY & VT)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°F)	2010's	19.0	21.3	29.5	41.8	55.5	62.0	68.5	66.4	59.9	48.2	35.5	25.7
	1980's	15.4	20.4	28.8	41.9	53.6	60.9	66.9	64.6	56.4	45.0	34.5	21.1
	Change	**3.6**	0.9	0.7	-0.1	1.9	1.1	1.6	1.8	**3.5**	3.2	1.0	**4.6**
Prec (")	2010's	3.0	2.9	3.1	3.6	4.0	5.1	4.1	4.4	3.9	5.0	3.2	4.2
	1980's	2.4	2.6	3.1	3.6	4.0	4.1	4.0	4.1	3.8	3.5	4.4	2.9
	Change	0.6	0.3	0.0	0.0	0.0	**1.0**	0.1	0.3	0.1	**1.5**	-1.2	**1.3**

Southern New England (CT, MA, RI) & Pennsylvania

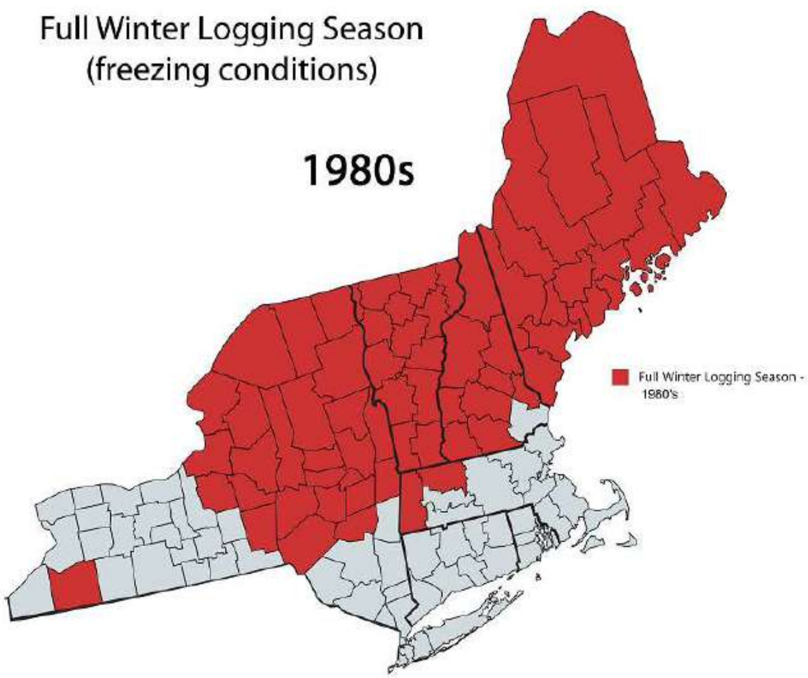
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°F)	2010's	27.0	29.2	37.1	48.0	59.6	66.7	73.0	70.6	64.6	53.4	41.6	33.8
	1980's	24.0	28.4	36.0	46.7	57.3	65.0	70.9	69.0	61.4	50.1	40.9	29.3
	Change	**3.0**	0.8	1.1	1.3	2.3	1.7	2.1	1.6	3.2	3.3	0.7	**4.5**
Prec (")	2010's	3.4	3.5	4.0	3.7	3.8	4.6	3.9	4.2	4.2	4.8	3.5	4.1
	1980's	2.8	3.3	3.9	4.5	4.1	4.5	4.2	3.5	3.1	3.7	4.9	3.0
	Change	0.6	0.2	0.1	-0.8	-0.3	0.1	-0.3	0.7	**1.1**	**1.1**	-1.4	**1.1**

Table 2. Monthly average temperature and precipitations differences between the 1980s and 2010s for eight northeastern states.

		Month												
State		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
CT	Temperature	3.4	0.7	1.0	1.0	2.0	1.5	2.3	1.8	3.5	3.7	0.8	4.6	°F
	Precipitation	0.0	0.0	-0.3	-1.5	-0.8	0.1	-0.6	1.0	1.0	0.4	-1.7	1.1	"
MA	Temperature	3.5	0.9	0.9	1.3	2.3	1.6	2.3	1.9	3.6	3.4	0.9	4.6	°F
	Precipitation	0.5	0.2	0.1	-1.1	-0.4	0.2	-0.6	1.0	1.1	1.3	-1.3	1.2	"
ME	Temperature	4.4	0.5	1.0	-0.3	1.3	0.7	1.7	2.1	3.7	3.0	1.2	4.5	°F
	Precipitation	0.4	0.5	0.2	-0.1	0.1	1.2	-0.2	0.0	0.1	1.9	-1.1	1.6	"
NH	Temperature	3.8	1.0	0.8	0.4	1.9	1.2	1.7	1.9	3.7	3.4	1.1	2.8	°F
	Precipitation	0.3	0.1	0.1	-0.5	-0.2	0.7	0.2	0.6	0.4	1.6	-1.3	1.5	"
NY	Temperature	2.9	0.9	0.7	0.0	2.6	1.5	1.5	1.3	3.0	3.1	0.8	4.4	°F
	Precipitation	0.5	0.4	0.0	0.2	0.3	0.7	0.3	0.6	0.0	1.4	-1.0	0.8	"
PA	Temperature	1.9	0.6	1.0	1.4	2.6	1.9	1.4	0.8	2.6	2.6	0.0	4.1	°F
	Precipitation	0.9	0.2	0.0	0.1	0.1	0.1	0.6	0.8	1.6	1.5	-1.0	1.1	"
RI	Temperature	3.3	0.8	1.2	1.6	2.3	1.5	2.4	1.9	3.2	3.6	1.1	4.8	°F
	Precipitation	0.6	0.4	0.3	-1.0	-0.2	-0.2	-0.8	0.3	1.1	1.1	-1.5	1.1	"
VT	Temperature	4.0	1.4	0.7	-0.4	2.0	1.2	1.5	1.9	3.5	3.3	1.1	4.9	°F
	Precipitation	0.2	0.2	0.0	0.4	0.2	1.4	0.4	0.0	0.0	1.1	-1.5	1.1	"
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	

darker shading = most significant increases

Figure 1. Northeastern US counties with frozen winter logging conditions in most years.



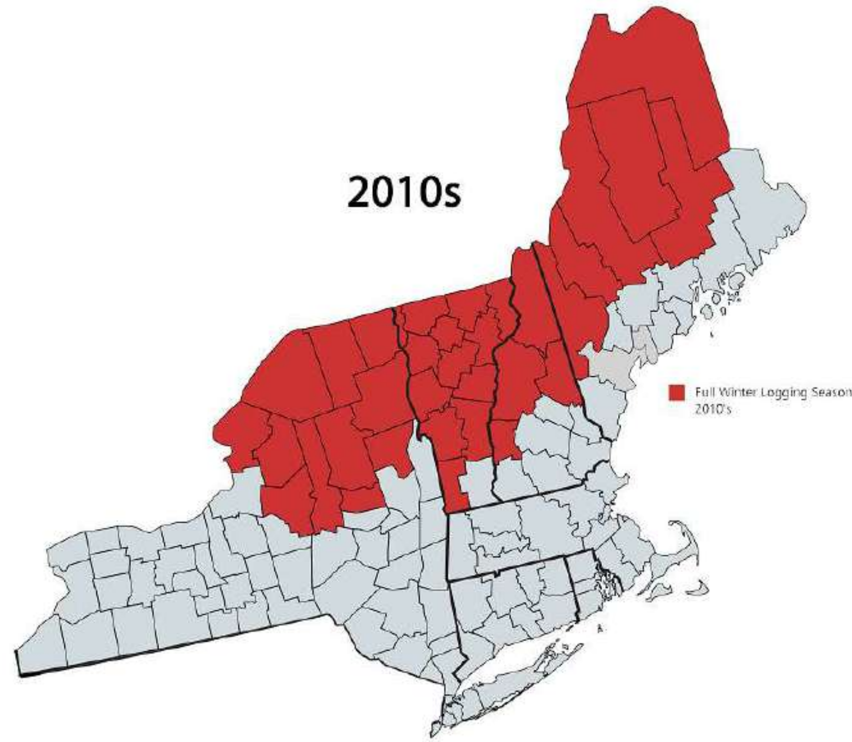
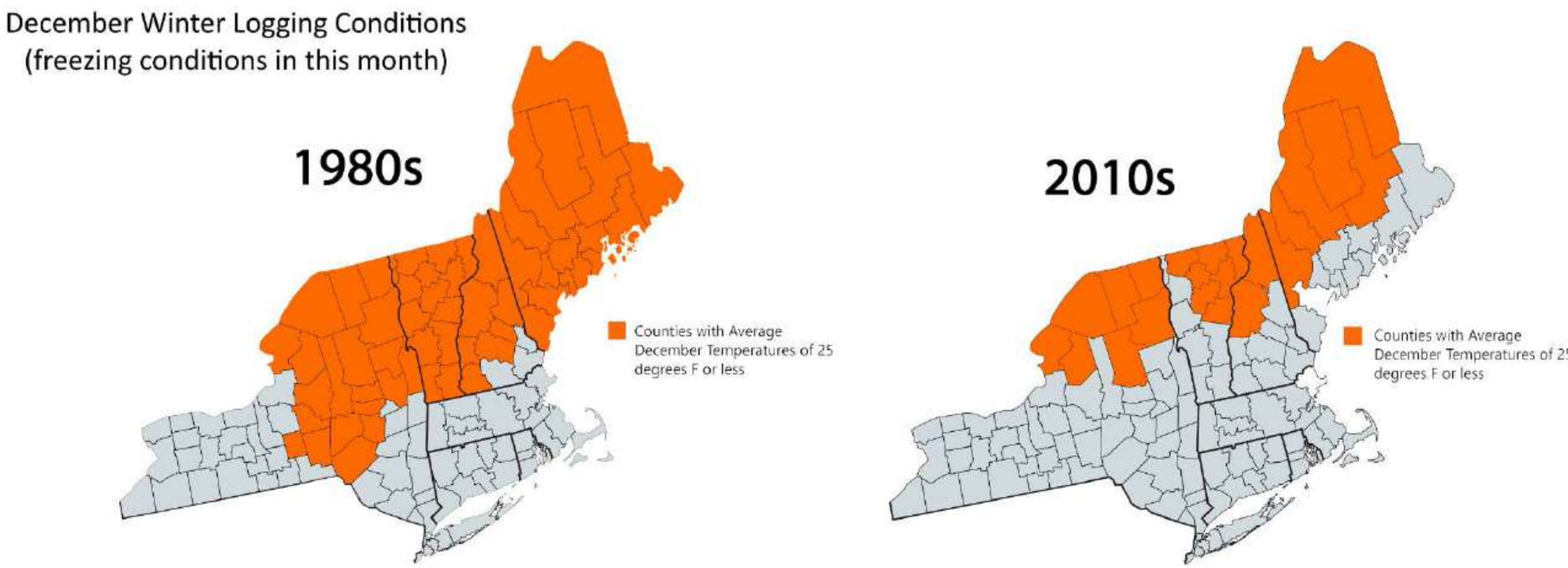


Figure 2. Northeastern US counties with frozen winter logging conditions starting in December most years.



Harvest Scheduling

Harvest Scheduling

Changes in seasonal weather patterns pose challenges to scheduling timber harvests. Shorter windows of time for harvesting, less predictable seasons and extreme precipitation events mean larger time spans are necessary to ensure successful completion of harvests. These factors change the approaches people in the forest products supply chain use in scheduling. While harvest scheduling is ultimately the purview of the forest manager, both timber harvesters and mill procurement teams must adjust their schedules to the conditions imposed by landowners and climate.

Forest Managers

Foresters interviewed in this study point out that what season a harvest could or should occur in has always been a primary question in harvest scheduling. The appropriate season might be influenced by access, operability, or regeneration concerns. Past understanding of the ground and weather conditions corresponded better to nominal ideas of what was expected or relied upon for each season. Some of those interviewed noted that these questions were easier to answer in years past.

In previous decades, harvest scheduling was simply coordinated with a glance at the calendar. Current conditions required a better understanding of stand-level soil conditions and water quality concerns. While site conditions are a primary consideration, access plays an equally important role in harvest scheduling.

It is possible for sites to be fairly operable under wet conditions, but inaccessible. This situation was cited in several interviews. Since long time periods often pass between harvesting individual stands, preparation for future harvests often reveals that access roads used in the past are now inadequate or that limited maintenance has left roads degraded over time.

Access limits come in several forms. Areas that can be accessed only via frozen road surfaces now have a shorter window of frozen weather to work with. In some winters, even this short window is unavailable. In other cases, roadbeds and drainage are simply inadequate to accommodate truck traffic.

Short stretches of road limitations can be overcome with wooden mats, gravel over fabric and similar improvements. Larger stretches of inadequate roads require a greater level of improvements, including widening, ditching and upgraded cross-drainage. In both cases, the cost of harvesting is increased and scheduled harvests require longer windows (multiple years in some cases) to ensure adequate access can be provided.

Matching harvest schedules with abundant seed years to ensure regeneration by certain species adds one more layer of complexity. Aligning weather and ground conditions with high seed production can cause repeated delays over many years and in some cases may prove impossible.

Forest managers report that longer contract windows for timber sales are necessary to ensure that work can be completed. One forester suggested that a sale that requires six month of acceptable ground conditions to complete warrants an 18-month contract window. This is especially true when timber sales are sold through competitive bid sales when buyers take higher risks by making payments in advance. Buyers need the higher level of certainty that comes with a longer contract window.

Both landowners and mills report that timber sale contract extensions have become more common. These extensions are driven by both the unreliability of weather conditions and by logging contractor availability. When ground conditions for harvesting area good, most logging contractors are fully committed and they can't be in two places at once.

From a landowner and forest manager standpoint, it is preferable to extend contracts than to allow harvesting when conditions are unsuitable. Sites that have very limited windows of operability require vigilant monitoring of conditions and enforcement of contract safeguards.

The various state-level Current Use programs in the Northeast require adherence to a timber harvesting schedule. Current Use enrolled properties receive a significant property tax reduction and are required to follow an approved forest management plan. Some of these programs allow greater flexibility or wider windows than others. All of the public lands foresters interview report that either multi-year scheduling windows or schedule revisions have been necessary for weather related conditions. It has been suggested that the larger landowners within these programs have greater flexibility to creating harvest schedules that allow them to move logging contractors around properties to harvest stands where the ground conditions are suitable. This allows landowners to meet harvesting goals and recruit and retain reliable loggers.

This dynamic approach to harvest scheduling seems to be a good idea, but it has been limited in actual practice by the conditions in some Current Use enrollment programs. Large landowners who are not enrolled in Current Use programs often follow this approach. In the long-run, all of their harvesting priorities are met. At the same time, they do a good job of protecting water, soil and residual forest stands.

A flexible scheduling approach has the added benefit logger retention. Loggers seeking to minimize downtime can naturally be expected to stick with landowners that find ways to keep them working. Large landowners report that there is simply not enough summer ground to keep all of the logging contractors they use working with on a regular basis. Spring ground is in short supply.

One large land management company is embracing new climate realities in harvest scheduling by formally classifying forest stands they manage as suitable for summer or fall harvests. They include a harvest operability ranking in all of their timber cruise sample plots. This information is aggregated to give an indication of seasonal harvesting potential.

In the past summer and fall were considered a single category. Now, there is general acknowledgement of a fall "mud season" that perhaps was not observed historically.

Fall harvesting conditions can generally be expected to deteriorate and eventually become unworkable before frozen winter conditions arise. Traditionally there were brief suspensions in logging operations for portions of the fall deer season, but now these suspensions are longer. As noted in an earlier section, October experiences, on average, over one and a half inches more in precipitation than it did thirty years ago. Novembers are actually both warmer and drier, but there is little drying power in the short days and leafless trees of this month.

State agency foresters who provide private landowners services, along with private consulting foresters, report that making harvest financially viable at a small scale or on small parcels is challenging.

These small timber harvests become "squeeze in types", as one county forester called them. Marginal harvests can easily become casualties to larger forces. It is easy for them to get lost in the shuffle and then put off for another year. Ideal harvesting weather and market conditions are more likely to be used for larger harvests.

Scheduling for Logging

Why don't forest managers simply restrict all logging during the least cooperative ground conditions? Some do, though most of these are public agencies. Too many seasonal restrictions would harm the viability of logging businesses. The supply chain must have loggers if timber is going to be harvested to fulfill forest management goals and supply mills with wood.

Logging is a capital-intensive business when newer and more expensive whole-tree and cut-to-length systems are used. The more a logger invests in equipment and support, the more revenue is necessary to sustain the operation. Sufficient revenue can be realized through a combination of high productivity whenever ground conditions cooperate and by operating as many days as possible. Changes in seasonal weather patterns have made this more difficult.

Comparative climatic data (NOAA, 2018) for locations in the Northeast show that there are approximately 184 days per year of possible sunshine, on average. Sunshine is not a requirement for logging, but it is a good indicator of the number of days when rain is less likely and, in some seasons, when soils are drying out.

A major logging equipment dealer in the Northeast suggests that mechanized loggers need eleven months of annual production to cover their costs and turn a profit that allows a business to grow. If there are 254 weekdays in a year, a full eleven months of these amounts to 237 days. Producing on this many days is a difficult accomplishment. Many loggers in the Northeast report producing between 180 and 220 days per year. The lower end of this range usually corresponds with smaller and less capital intense harvesting systems.

As a general rule, most loggers in the Northeast can count on approximately 140-160 days per year of relatively trouble-free weather and ground conditions, if appropriate safeguards are followed. Where do the additional 30 to 70 days come from? A combination of factors makes them available and none of them can be attributed to chance.

Careful project management ensures the logger is on the right site at the right time. Some of this is the loggers doing, but often this requires cooperation from forest managers and mills.

All administrative hurdles that might prevent a transitions from one job to another must be addressed in advance. These include contracts, insurance certificates, bonds and related matters. Productive days should not be lost to administrative oversight.

Trucking of wood products and equipment must be handled in a timely fashion. Careful transitions between jobs sites that keep lost productive time to a minimum require sound planning.

Advance preparation of jobs sites can ensure that harvesting can begin almost immediately once equipment is moved. This requirement has spurred many loggers to purchase excavation equipment.

Many project planning items that help maximize productive time are the responsibility of the logger, but some are beyond their control. This is especially true when contract logging work is done for large landowners or for mills. In these cases, developing cooperative relationships is an essential part of keeping work on schedule.

Mill Scheduling

Hardwood sawmills in the Northeast are the mill types most often involved in purchasing timber and scheduling harvests, with other mills more likely to rely on suppliers of intermediate products that are harvested by others. Hardwood sawmills often purchase timber from private non-industrial landowners who have an incomplete understanding of how the mill tries to balance the need for supply with compliance with contract requirements and environmental safeguards. The window involved with a timber sale to a sawmill, from planning, marking and showing, through contracting, harvesting and clean-up can often take one to two years. The process will often take up this entire extended window of time, regardless of the size of the property or the volume and value of the timber.

Climate change has expanded this process in ways that can make it longer. For example, harvests that might be ideal under frozen winter conditions must be postponed if these conditions do not materialize. High soil moisture and unfrozen ground can create disastrous conditions if harvesting takes place at the wrong time. There are smaller periods of opportunity for harvesting than in the past.

This shorter opportunity zone based on ground conditions mean that many mills are looking for longer contract windows or asking for multiple extensions. It has become commonplace to request either two winter seasons or two summer seasons as conditions within timber sale contracts.

The forestry community has come to recognize these timing realities. Private sector consulting foresters have more flexibility in this regard than public lands foresters, but they inform landowner clients and properly manage their expectations. Many consultants now offer eighteen month to two-year timber sale contracts, along with adequate provisions for reasonable extensions. Keeping landowners happy with the results of what is often a once-in-a-generation timber harvest often means minimizing the potential negative impacts from harvesting under the wrong ground conditions.

Loggers and sawmills both note there are some foresters who are not yet taking climate realities into account. A standard practice for safeguarding ground conditions has traditionally been to limit harvesting to winter or dry conditions. When historical winter conditions do not materialize or soils remain saturated throughout the summer, the harvest is either postponed or takes place on saturated soils. This is especially true for Southern New England, Southern New York and most of Pennsylvania, where frozen winter conditions have become uncommon.

Public agencies have less flexibility. State and federal foresters are often subject to well-intentioned administrative oversight that has not yet factored climate realities into contracting guidelines. For example, it is difficult for some public agency forester to secure longer scheduling and timber sale contract windows, based on administrative guidelines and oversight.

Public agencies must negotiate these hurdles to accomplish successful climate adaptations. Interviewees noted that this requires a combination of acting on those things within their control, such as the timing of timber sale bid offerings, and providing feedback on contracting to centralized oversight that is not knowledgeable about forestry practices.

Once a sawmill has purchased a timber sale, a number of factors dictate their schedule for harvesting it. First are the contractual safeguards or restrictions. Other considerations include the availability of the logging business or crew that they believe is best suited for the work and the type and volume of wood involved..

The species included in the sale and the quality of the wood also play a role in scheduling. Some periods of the year, such as spring and early summer, are more prone to a loss of bark in harvesting. This loss can impact log values if these are part of a resale program and not sawn at the mill.

Most of the summer season is off limits for exporting logs because of the risk of devaluing the wood. Care must be taken to avoid excess inventory of certain species under hot or dry conditions. This is because staining can occur in logs that are not sawed in a timely fashion, devaluing them significantly.

Sawmill contract loggers report they often encounter winter only logging restrictions on timber harvests that have been put in place by consulting foresters or by the landowners themselves. These conditions are a holdover from when winter meant frozen conditions, but in many parts of the Northeast, winter is simply an extended wet period.

Some of the loggers who primarily do contract harvesting work for sawmills note that contract deadlines dictate a sawmill's harvesting schedules far more than ground conditions. Market conditions play a role in this as well. As a result, the contract loggers are sometimes asked to do jobs under conditions that they believe will not accommodate skidding without violating best management practices for water quality.

Requests by sawmills for contract extensions have become more common. While many contracts have clauses allowing for extensions based on reasonable, weather-related causes, it can be difficult to identify such a cause for an individual sale. The sawmill is juggling multiple considerations in deciding where to harvest from among the timber it has purchased, so that reasonable windows of opportunity for some locations are foregone.

A result of these foregone opportunities in pursuit of larger supply interests is that contract extensions must often be purchased. It is preferable to pay a bit more for the opportunity to harvest the timber than incur the greater loss of both the purchase price and the supply volume.

One of the large sawmills in Vermont procures some of its supply on both the Green Mountain and White Mountain National Forests,. The US Forest Service sales come with five-year contracts but have traditionally only allowed harvesting under winter conditions. The Forest Service will add days to the contract to make up for time lost to poor weather.

The Green Mountain National Forest revisited their winter-only conditions on a recent timber sale. The winter months were not providing adequate conditions, so the USFS had their soil scientist examine the timber sale site. Based on this analysis, they then allowed summer harvesting on portion of the timber sale area. This adaptation accommodates both the sawmill's supply concerns and the National Forest's desire to maintain its harvesting schedule.

Adaptations Summary for Harvest Scheduling
• Longer harvest scheduling windows by forest managers to meet requirements for ground conditions, regeneration and market access;
• Changes in definitions and expectations for seasonal harvesting conditions by forest managers;
• Improved project management by loggers to maximize production time and minimize time lost to ground conditions and job transitions;
• Concurrent operation of multiple harvesting sites by loggers to ensure at least one site is harvestable at any given time; and
• Longer timber sale contract terms by mills that purchase timber.

Best Management Practices

BMPs and Climate Adaptation

Best management practices for water quality (BMPs) have become a commonly accepted standard for logging in the Northeast. In most states, these practices are voluntary, though they have become integrated into many timber sale contracts, conservation easements and land management certification standards. Acceptance of these standards has been influenced in part by adaptation to climate change. What was originally thought of as a burden in logging has become an important safeguard of productivity and an occasional means of achieving marginal increases in production.

Depending on the state, BMPs (called Acceptable Management Practices or AMPs in Vermont) were first introduced in the 1980s and 1990s. While there was concern about water quality and some general guidelines for preventing erosion during logging prior to this time, introduction of formal BMPs was part of a nationwide trend. Many state-level BMP publications are in the form of illustrated guides that show how to implement structural practices to prevent sedimentation of streams and alteration of wetlands.

Prior to the existence of formal BMP guidelines, the emphasis was mostly on avoiding water quality violations under the law and obvious examples of erosion that landowners, loggers and foresters found unsettling.

Many of the foresters and loggers interviewed for this report point to dates around 2000 as the start of real BMP compliance pressure. About half of those interviewed pre-dated BMPs and had worked through the implementation process. Others entered the workforce after BMPs were firmly in place and have followed them throughout their careers.

BMPs can be a mandatory component in certain situations (e.g. contractual requirement) and in certain locations (e.g. conservation easement requirement). In general, landowners and foresters employ and reference BMPs in making their expectations for harvesting practices known to loggers.

In Vermont, AMPs are required for all properties enrolled in the state's Current Use program. For these properties, AMPs must be in place during and after timber harvesting. Since a significant portion of the private forest land in Vermont is enrolled in this program, widespread implementation of these practices is evident, despite occasional violations.

According to some interviewees, third party certification has increased compliance with BMPs on some of the larger properties in the region, including both private and public lands. Annual certification audits look for evidence of BMP compliance and the auditing process provides the opportunity for broader applications and innovation. These interviewees believe that this has had a positive influence on other working forests that are not third party certified, because they are managed and harvested by the same people as the certified properties.

The widespread adoption of BMP's 20 years ago coincides with the changes in seasonal temperatures and precipitation described earlier. It took most of a decade of change for many in the forest products supply chain to grasp that these changes were more than simple annual variations.

The unpredictability of seasonal weather patterns and the increasing frequency of rain events has spurred further innovation in the use of BMPs. For example, planning and attention to maintaining structures like culverts and water bars during active harvests have shifted BMP compliance from an after-the-fact action to one that is fully integrated during the harvest.

Initial resistance to BMPs has given way to compliance and innovation, according to foresters working in the region. While loggers were at first unfamiliar with control devices such as water bars, over time they have improved upon the design and installations that were part of the initial BMP requirements when they were first put in use.

Loggers have adjusted their practices so that they address BMPs through every stage of their operations. Since most loggers have financial pressures requiring them to harvest as many days as possible, they must address BMPs through advance planning, placing water diversion structures and crossings prior to harvesting, and maintaining these structures throughout the harvesting window.

Behavioral Best Management Practices

In contrast to structural BMPs that protect resources through physical installations such as bridges or water bars, behavioral best management practices are those relating to decisions to start, forego or suspend harvesting. This distinction is important, because behavioral BMPs are often unrecognized, but can involve significant costs. Anytime loggers must idle production, they incur financial costs, which may also impact landowners and mills.

Delaying a start date for harvesting will idle a logging business if there are no alternative harvesting sites available. Delays on smaller harvesting jobs can have a significant impact on landowners when this delay results into a substantial postponement of harvesting for six months to a year or more. Delayed starts will sometimes impact the overall supply of a wood processing plant.

Foregoing a harvest has similar impacts, though they may be longer lasting. Smaller harvesting sites or those with challenging access or operability may be put off indefinitely.

Suspending harvests already in progress has the most direct impact on logging businesses. Fixed costs to these businesses continue to accrue, even as revenue is interrupted by a lack of production.

Loggers have adapted to the start-stop pattern of logging necessary to adhere to BMPs and new climate realities in several ways.

For example, loggers must pay particular attention to skidding and forwarding - the activities that are most likely to be curtailed during wet weather with soft ground conditions. Loggers work to maximize skidding or forwarding when conditions are right. This sometimes involves segmenting jobs into areas by skidding potential. This segmenting involves skidding in the wettest areas whenever ground conditions allow, with better drained areas completed during inevitable wet periods.

Another option is stockpiling materials on the landing as much as possible to ensure fewer interruptions in overall production. In this way, loads of wood can be processed and trucked even when skidding is suspended.

On sites where landing and processing areas are subject to size limits, loggers might add a second staging area nearby with a well-drained skid trail in between this and the main landing. When skidding is suspended for most of the harvest area, wood can still be skidded to the main landing from the secondary one. However, several loggers noted that some landowners and foresters are not open to this approach, most often because they do not wish to have a second-high impact area on the property.

Finally, production shutdowns are a standard response to unsuitable ground conditions. Landowners, foresters, or the loggers themselves may make the call to suspend work. These decisions are often difficult or conflicted, as each party works to meet their individual needs.

Production shutdowns are a difficult and expensive reality for forest products professionals struggling with climate-related impacts. For example, foresters face conflicting pressures to protect water quality, live up to landowner or third-party certification expectations, keep the mill supplied and maintain a good working relationship with the logger. Loggers must continually produce revenue to make payments and to keep workers fully employed and at the same time maintain a reputation that protects future work opportunities. These examples illustrate how loggers are adjusting their behavior to comply with BMPs, while still meeting the demands of running a profitable business in the forest products industry.

Identifying the costs involved and who bears them is a key point in understanding the strain on the forest products supply chain caused by climate change. As warmer and wetter conditions become more common, loggers will increasingly need to adjust to meet the standards of BMPs. However, the costs of behavioral BMPs often go unrecognized.

BMP Climate Stress

Forestry staff from natural resource agencies in several of the Northeastern states report a noticeable uptick in BMP violations. Most point to a direct link between these violations and a growing number of days when soil moisture makes compliance more difficult. These public agency staff members point to more work under soft ground conditions, corner cutting on installations and a lack of patience by some parties as the cause of violations.

These same public agency staff members acknowledge that BMP violations are driven more by financial realities than disregard for water quality. The costs of doing business have gone up even as it has become more challenging to balance production with BMP compliance.

Several of the loggers who were interviewed acknowledged this trend. They frame it as "*pushing the limits*" and "*doing things they have never done in the past*".

When you divide across the board increases in the cost of operating by a shrinking number of days with acceptable ground conditions, these admissions are unsurprising. Fixed price production work that dominates the logging opportunities in many parts of the Northeast makes it difficult to halt operations.

The increase in BMP violations may also be associated with more thorough monitoring by regulatory agencies. Not only are agencies increasingly emphasizing monitoring, but they also have access to new technology, such as widespread and timely LIDAR and satellite photography, that can detect more violations than in the past. If loggers are maintaining productive work schedules on par with those they assumed when financing equipment, even as seasonal operating conditions experience marginal deterioration due to climate change, BMP violations are an inevitable result.

Excavation Equipment on Logging Sites

Many loggers mentioned that in recent years, a bulldozer or small excavator is necessary for BMP compliance, preparation work and to maximize operating time under conditions of high soil moisture. This fact is heavily influenced by climate change and can therefore be considered a climate adaptation. Under past conditions, BMP compliance was thought of as after-the-fact cleanup work and little site preparation or mid-harvest excavation work was done. Excavation equipment was considered an unnecessary by most loggers.

Loggers and foresters characterized excavation equipment as "*absolutely critical*". In some instances, the ownership of this equipment determines whether or not a logger will be given a harvesting opportunity.

One logging contractor described the bare necessities in terms of excavation equipment for a large production oriented whole tree harvesting crew, including both a bulldozer and an excavator, mentioning the D5 Caterpillar and a 200 series 20-ton excavator as example of sizes.

A D5 bulldozer has a track width of 7'7", ground clearance of 9", with 6'2" spread between the inner edges of the two tracks. This machine is about 15' long and has a blade width of 10'3"

A John Deere 200 series excavator has a track width of 10.5', with a track length of 12'. This machine has 1.5' of ground clearance between the tracks. The longest arm available for this machine has a horizontal reach of 32'.

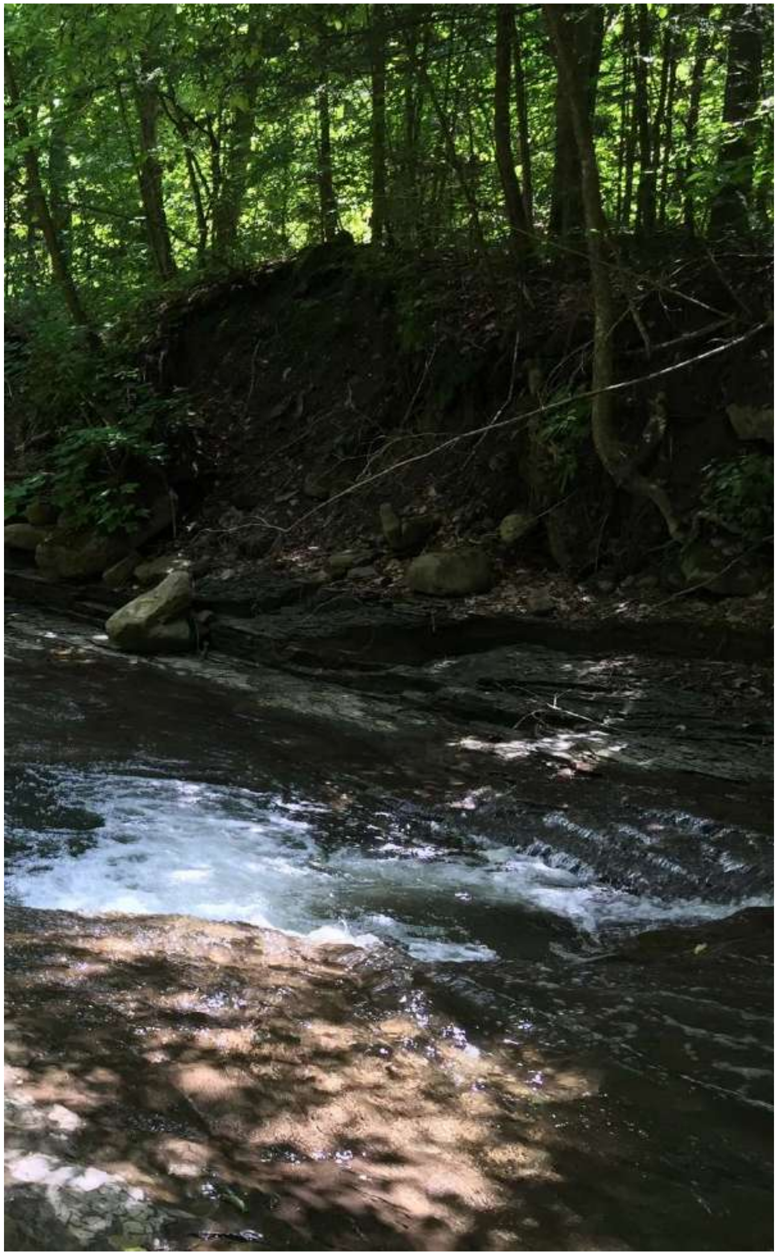
Often this excavation equipment must be pared with a dump truck. The dump truck is used to haul material for preparation work, such as building a central landing site.

Conclusions

Stewardship of forest resources is the starting point for the forest products supply chain. As working forest activities have become increasingly regulated over the past several decades higher expectations are now in place. Resulting guidelines place stricter boundaries on how forest professionals conduct stewardship activities. BMPs for water quality protection are one important example of these new regulations and guidelines.

The interplay between climatic changes and BMPs can place multiplicative burdens on forest workers. An era of heightened protection of water quality has corresponded with changes in seasonal weather patterns and more intense storm events. Nevertheless, loggers and others in the forest products industry continue to innovate to meet environmental standards while at the same time supply wood to meet market demands. Moving forward, it will be important to recognize the impacts of both climate and regulatory influences on the forest products industry.

Adaptations Summary for BMPs
• Improvements in structural BMPs;
• Advance installations of structural BMPs;
• Enhanced maintenance of structural BMPs during harvesting;
• Acknowledgement and sharing responsibilities for behavioral BMPs; and
• Widespread use of excavation equipment throughout the timber harvesting process.



Roads

Roads

Functional road systems are essential to the forest products industry, but several climate-related factors are influencing the utility of roads for forest workers. Warmer and wetter conditions, as well as increased frequency of extreme weather events are resulting in more washed out and rutted forest roads. Some other issues include a lack of road upgrades or maintenance, or roads that were not adequately built for future needs.

A common theme in discussing of roads with interviewees is that road that worked well for forest operations in the past no longer do so. Climate stress from longer wet seasons, coupled with increased traffic during operations and in some cases wider trucks and longer trailers, have required upgrades. For example, a state forest might have some bridges that are too narrow or placed on a curve that will not accommodate a tractor trailer. If the previous use of the road for a timber sale was a generation or two earlier, the road was probably adequate at that time. New traffic and climate demands mean may mean the road is no longer serviceable without improvement.

Public agencies have seen road maintenance costs rise even as maintenance budgets shrink or are diverted to a broadening workload. Often the increased workload is due to climate-related issues such as the spread of forest pests and invasive species.

One option on public lands is to build the cost of capital improvement work on roads into individual timber sales. For example, timber sale contract requirements of purchasers might include upsizing and replacing culverts, adding gravel, and raking road surfaces. Some state agencies have broad leeway to include such conditions into sales and others must be able to make specific ties of necessity to individual timber sales. In either case, some of the value of the timber that is sold gets incorporated into necessary stewardship of the land.

Road improvements on private lands are another matter. One logger explained that managers of the large land base where he works will only go so far in terms of road maintenance.

"If we aren't happy with it, we have to spend our dime to fix it" he explains, adding that the quality of roads he is asked to put his trucks on is a shame.

Road maintenance on single purpose woods roads has often been subject to skimpy budgets. Road maintenance might be ignored or merely superficial until a timber sale is pending. In other cases, it is deferred until immediately prior to sale of the land. Many of the larger timberland holdings in the Northeast have changed ownership multiple times in the past three decades.

Although the lack of road maintenance may not be a new concern, new climate realities are exacerbating the effects of poor road conditions. With warmer and wetter weather, timber operations require roads in good condition to avoid damage from forestry equipment.

One solution is to build better roads to begin with, using higher-quality materials and proper engineering. These roads could handle extreme weather events such as intense rainstorms. Public agency foresters interviewed for this report lamented the fact that road engineering is often seen as too costly. On private lands, engineering is rarely even considered. Recognizing the constant temptation to skimp on maintenance, it would be advisable to spend a little more for proper road construction in the initial stages.

Interviewees acknowledged that road systems have to accommodate both a greater flow of traffic and a greater flow of water from storm events. In other words, the stresses on roads are coming from both changes in the climate and changes in expected uses. While loaded weights have not necessarily increased in the past two decades, the level of traffic during active harvests often has.

One of the means of preventing washouts and maintaining good roads surfaces that can withstand storm events of increasing intensity is to use crushed stone. There is significant cost in this, mostly in transporting the material to the site.

Crushed stone with irregular edges can form a tightly compacted surface. Larger stone is far less prone to runoff loss. Since crushed stone can be costly, it is often used only for problem areas such as hills and curves that are most prone to erosion. Some landowners approach this as an on-going process. By dedicating some of their maintenance budget to addressing the worst of their road problems with crushed stone, roads are steadily improved each year and washouts are far less frequent.

Winter Roads

A winter road is one that is frozen in place, with no gravel or stone providing a base. A combination of soil, snow and ice are frozen together to create the road surface. The route for the road is cleared and the soil laid bare, so that frost can be driven deep into the ground. Running water must be removed from the road surface just as it would be for any road. The road is kept clear of snow and a heavy drag is used to smooth it and help drive the frost far into the ground. Once fully frozen, a road of this type will accommodate loaded log trucks and other equipment. Such roads are often smoother than gravel roads are in the summer.

Winter roads have historically been used to reach remote locations that do not have access to improved roads. In such cases, terrain and infrequency of use have not warranted the expense of building an improved gravel road.

In some cases, forest managers make winter roads themselves, or hire qualified sub-contractors to do this work.

In others, the loggers who will be using the roads are responsible for building them. Depending on the skills of the logging contractor, they may need some instruction from someone with experience in making winter roads.

The opportunity and the ability to use winter roads for accessing remote timber harvests have become less common. Truly cold and freezing winter weather has become less reliable in many locations in the Northeast. Loggers who know how to make winter roads are less common than in the past. As past generations have retired and the opportunities for applying winter road skills decrease, this ability is becoming a lost art.

Diminished opportunities and abilities to employ winter roads have prompted a practical adaptation by the managers of many large timberland properties. When the expense of extending gravel roads is not warranted, these forest managers are upgrading their winter road networks in ways that enable them to be frozen in place quickly if weather conditions cooperate.

Climate-smart winter roads are essentially the same as gravel roads, except that they lack gravel. Water crossings, cross drainages and ditches are in place. All that is needed is snow, cold conditions and some equipment time to grade the road surface and drive the frost into the ground. This adaptation addresses both a lack of winter road building skills among the logging contractor workforce and the shorter and warmer winter conditions.

Public Roads

Public roads are subject to posting to greatly reduced weight limits under conditions when they could be damaged. Typically, this is done at the end of the winter as the frost comes out of the road. This situation is most significant, from a forest operations standpoint, at the point where the public road is first accessed, as there are generally no alternative routes. Posted roads can effectively rule out trucking forest products.

Access from forests to public roads most often occurs on town roads, under the jurisdiction of a town highway supervisor or road foreman. These roads are often gravel, though an increasing number have been blacktopped in recent years. Seasonal damage to gravel roads can usually be easily remedied with routine grading and raking. Damage to blacktop roads is more difficult to fix.

Historical road posting patterns followed the weather in a predictable fashion and tended to correspond with the end of winter harvesting. Some of those interviewed report this pattern remains in place. In other cases, road posting is occurring earlier and in some cases even during mid-winter, during periods of thaws.

Highway superintendents have traditionally had a shared culture with working landscape people and understand their needs. Some of those interviewed expressed concern that this shared culture is being lost and the flexibility to suspend or alter road posting may be lost with it.

A representative of one large landowner reported that a town attempted to bill the landowner for work on a public road after trucking was done on the road for a timber sale. Another reported that one town was requiring that a performance bond be posted before forest products could be trucked on its roads. Both situations involved vehicles licensed for over the road traffic, rather than damage by the improper use of logging or excavation equipment on public roads.

Extreme weather events that damage public roads impact all of their users, including the forest products industry. A hardwood sawmill in Vermont reported that the road washouts after Hurricane Irene create significant challenges in trucking logs from harvesting sites that were operating at that time. This risk, though share by everyone who relies upon public road, is difficult to mitigate against.

Conclusions

Road construction and maintenance are essential to forest operations and are increasingly seen as a climate-related issue. The impact of extreme weather events can be rapid and even a single washout can bring access to harvesting sites or delivery of wood products to a halt. Moving forward, it is important to build and maintain roads to high standards to minimize damage and maximize utility. In many cases, forest workers can no longer rely on predictable weather conditions to accommodate road use and prevent damage.

Adaptations Summary for Roads
• More frequent maintenance of gravel roads;
• Added capacity in drainage structures;
• Increased use of crushed stone for weather-proofing
• Upgraded winter road networks that require less effort to freeze in place;
• Awareness and cooperation in local road closure policies; and
• Use of alternative routes when public roads are damaged unexpectedly by storm events.

Adaptations in Timber Harvesting Systems

Adaptations in Timber Harvesting Systems

There are three main ground-based timber harvesting systems in use in the northeast. These include tree-length (TL), cut-to-length (CTL) and whole-tree harvesting (WTH). The extent and manner in which each of these systems is used has been influenced by multiple factors, including changes in the climate.

Tree-length systems involve hand-felling and limbing trees with a chainsaw in the woods, and then transportation of tree stems to a central landing site by a cable skidder. Bucking into lengths and sorting into product types is done at the landing, where trucks are loaded.

Cut-to-length systems use a single machine to fell and process stems into merchantable products in the woods. A forwarder then carries these stems and sorts them into piles for loading at one or more road front sites for loading onto trucks.

Whole-tree harvesting systems use a feller-buncher to cut and bunch tree stems. A grapple skidder then pulls these bunches of whole tree to a centralized landing. A loader and slasher are used to cut these tree stems into merchantable products and then sort and load them. Tree tops are either chipped into a trailer for transportation to a market or pulled back into the woods by the grapple skidder.

Leon and Benjamin (2012) found that, in terms of volume produced, WTH systems are the dominant one used in the Northeast, followed by CTL and TL systems. Each of these systems has a presence in nearly all areas. The WTH systems tend to be most common in Northern Forest counties, while TL systems are most common in other areas. CTL systems have found niches throughout the region and there are small areas where they dominate production.

In practice there is significant crossover and pairing of each of these three main types of harvesting systems in the region. There is also a small amount of alternative harvesting going on with low-impact, low production systems such as tractors and small tracked machines, which are variations on the tree-length system.

Whole Tree Harvesting

Several factors influenced the transition to whole tree harvesting in the 1980s and 1990s, especially in the Northern Forest region. This system is well-suited to harvest low quality trees at a high intensity as commonly prescribed in the Northern Forest. Some loggers switched to whole tree harvesting as they got older because it involves less physical labor. It also creates the option of chipping tree tops and low-quality stems in locations where there are markets for dirty wood chips

The WTH system has main skid trails that are heavily trafficked. Soft ground conditions and rain events can render these trails unusable mid-harvest. General skidding conditions have worsened over time with increased precipitation in some months and lack of freezing conditions in others. WTH loggers have adapted to this situation by reinforcing their skid trails with the tops of harvested trees.

Whole trees are delivered to the landing with a grapple skidder, where they are delimbed and cut into merchantable products. Tree tops and limbs that cannot be made into merchantable products are carried back into the woods by the grapple skidder and placed in soft and wet spots in the skid trails. Repeated traffic over these tops mashes them into place.

WTH loggers in some locations are faced with a utilization decision about topwood and limbs. In some cases, there is a market for wood chips as hog fuel. This is a low value product with a high tolerance for the bark, leaves, and dirt that accompany these wood chips. The logger can opt to forego this market and instead work to ensure continued productivity by using this material to reinforce trails. The alternative is to chip topwood and limbs and risk losing productive time due to trails that are periodically unusable.

Many loggers divide topwood and limbs between both uses, opting not to chip the smallest and muddiest tops and limbs. Loggers with robust roundwood markets and tight delivery schedules – usually those with the highest capital investments – make a conscious decision to forego hog fuel chipping opportunities in order to maximize time spent on overall production.

One cooperative strategy between foresters and WTH loggers is for the forester to identify a small stand or location for a group selection harvest in which all trees are removed. This location will have a high concentration of low-value, undesirable tree stems. Much of the wood harvested in this location will be used in reinforcing main skid trails for the entire harvest area.

However, some landowners do not want skid trails full of tree tops. This practice that works so well for skidding makes them very difficult to walk on afterwards. Some foresters question if trails will be usable in future harvests if they are full of decaying organic material.

WTH systems in the northeast have commonly used four-wheeled grapple skidders. The use of six-wheeled grapple skidders is a more recent development, partly in response to climate challenges. Loggers like the fuel-efficiency of these machines and the fact that one machine, with one operator, can pull more wood than the more traditional four-wheeled grapple skidder. With fewer potential days available for harvesting because of soft ground conditions, finding ways to decrease costs and increase production on the days that are available is important.

Certain foresters do not like the size of the six-wheeled machines, believing they have too much potential to do damage to the residual stand. There are clearly some sites and silvicultural prescriptions for which they are poorly suited, but the same can be said for the WTH system in general.

Cut-to-Length Systems

Sentiments opposed to larger scale logging operations, shared by many, are part of the reason for the rise to cut-to-length (CTL) systems in some locations of the Northeast. There is a general sense that carrying wood in a forwarder has less impact than skidding whole trees or intact tree stems. An added feature has been the ability of CTL systems, under the right circumstances, to remain in production when soil moisture conditions might rule out skidding.

In the Northeast, new and almost new CTL systems are more capital intensive than WTH systems, in relation to productive output, for general harvesting conditions. They also require greater operator skill, which can increase labor costs. This system is more productive than WTH under the right conditions (timber size, harvest intensity, forwarding distance). The CTL system therefore requires these conditions under production logging contracts or requires price adjustments under more typical Northeastern conditions.

Loggers have adopted or tested CTL systems for a variety of reasons. The chief climate influence is the belief that forwarding has less impact on trails than skidding and therefore there is a gain in productive up time. This has proven true in some situations. Some of those who were interviewed noted that forwarding has a great deal of rutting potential under certain conditions and that this must be considered in harvest planning.

Large forwarder loads sizes are one means of compensating for the long forwarding cycle times common to many Northeastern locations. Unfortunately, larger loads have greater potential for rutting trails.

Several CTL advantages in hedging against climate-related risk were cited by logger and foresters, including:

- Less direct trail impact than skidding;
- Potential to gain productive days under wet conditions;
- Smaller landing sites need less climate- proofing;
- Forwarders can readily corduroy trails;
- Processors can place tops under tracks for flotation; and
- Processors can move stems away from areas not suitable for forwarders.

Other considerations driving CTL adoption include a desire to minimize residual stand damage and to decrease labor costs. In general, a CTL system accomplishes the same harvesting steps with two machines and operators as the WTH system does with three and sometimes four machines and operators. The CTL system may or may not accomplish the same tasks in the same amount of time, but CTL harvesters can process wood quickly under the right conditions. For this reason, some people believe CTL systems give loggers greater control of the harvesting rate.

Foresters and loggers report that the cost of building trails for forwarding surprise some loggers new to the system. While CTL systems require less landing space than WTH and some TL systems, they do need room to pile sorted logs and safely load trucks. Trucks require access from public roadways. This will involve preparation work, often with excavation equipment and materials. CTL systems are more productive when trails have been established in advance, including corduroy improvements to wet sections. This work requires planning and should be done far enough in advance so there is no loss of productive time. All of these CTL support needs incur costs.

CTL was tried in some locations in the Northeast and was not financially successful. CTL loggers note that foresters who like the results and relative impact of CTL systems do not always understand the harvest intensity and locations where they are suited. Some report they were encouraged by promises of higher payment rates for CTL services that never materialized. Many of these loggers went back to WTH systems.

Some of the CTL loggers in the region entered the business without prior experience with other systems. Given the realities of the timber supply, markets, landowner expectations and seasonal weather patterns, CTL just seemed like the best approach to them. In theory, CTL should have an advantage in productive uptime because forwarding could be done under softer ground conditions than skidding. Forwarder trails will sometimes hold up longer during thawing conditions than skid trails. Even CTL systems can have difficulty finding enough productive time. Finding ways to produce more by working more days and more hours each year is a common theme of conversations with CTL loggers.

One prominent CTL logger in the region reports their initial and reachable goals for production machines were 1,200 hours per year, 10-15 years ago, and they now sometimes struggle to reach 1,000. This is a significant loss of productive time and much of it can be attributed to unsuitable harvesting conditions arising from changes in temperature and moisture patterns.

One CTL contractor reported a nearly four-fold variation in productivity on the jobs they do. This requires either a large variation in stumpage or contract rates, or sufficient revenue from the most productive jobs to cover the costs of the least productive.

Tree-Length Systems

The tree-length system is best suited to lower intensity harvests of larger and more valuable tree stems. In the 1970's virtually all harvesting in the region was done with tree-length systems. At that time, some loggers were still using tracked machines but use of the newer wheeled cable skidders became common from then on. This system is readily scalable on individual harvesting sites, often by adding or subcontracting for another cable skidder, operated by a worker who also felled and limbed trees.

Harvests of large, mature sawtimber are less common in the Northeast than they were in past generations. The largest tracts of land tend to have lower quality timber and requires higher intensity harvests. This has contributed to a general decline in use of the TL system.

TL systems persist in the Northeast for two reasons. First, there are large sawtimber harvests occurring in many locations – particularly those closest to hardwood sawmills. Second, these systems can often be used with what several of those interviewed termed as "*patience*." This means that loggers using the TL system can afford to wait until ground conditions improve more so than those with other systems, because of the lower level of capital investment in their equipment.

When ground conditions and BMPs require suspending logging operations to protect water quality, the logger continues to incur fixed costs. TL systems are far less capital intensive than WTH and CTL systems. This means that the cost of suspending operations is far less. TL systems cost less and many of them involve minimal or no debt service. This makes idling these systems less costly.

Even if tree-length systems carry less debt, these systems must ultimately produce to be financially sustainable. TL loggers have adopted several methods of extending their productive processes during conditions that are unsuitable for skidding.

As discussed in an earlier section, excavation equipment has become a necessity for most loggers. TL systems often have a bulldozer to serve this role, performing site preparation, clean up and mid-harvest BMP compliance work. These same machines can often be used to bunch felled and limbed trees when conditions are too soft for skidding. Performing this work with a tracked machine minimizes ground damage and makes skidding time more productive once ground conditions are suitable.

Absent the ability to skid tree stems during unsuitable ground conditions, many small-scale TL loggers will fell and limb trees or process tree-length stems on the landing site. Skidding time is maximized when weather conditions are positive, because other functions have already been performed or can be turned to when skidding is not possible.

Conclusions

Each of the three main ground-based harvesting systems places a role in the Northeast, due to the diversity of ground conditions, timber types, stocking levels and silvicultural prescriptions. Each of these systems has evolved in uses, methods and equipment types over time. Much of this evolution has been in response to climate-associated risk that threaten the amount of productive time available.

Adaptations Summary for Harvesting Systems
• Ground-based harvesting system choices have been influenced in part by climate issues;
• Due to climate stresses, whole-tree harvesting loggers have made alterations in methods and equipment mixes;
• The cut-to-length harvesting system has been used in some cases to extended productive time during wet or soft ground conditions; and
• Tree-length systems persist, in part, due to the lower capital investment required and the ability to partially or completely idle under unsuitable ground conditions.

Wood Procurement for Mills

Wood Procurement for Mills

Climate change impacts of the harvesting season have a strong influence on the wood supply for mills in the Northeast region. Paper mills, sawmills and wood energy mills that produce wood pellets or electricity must all secure reliable supplies during seasons and periods of increasingly unreliable harvesting conditions. Strategies and tactics for coping with this uncertainty are detailed here for several types of mills.

Pulp and Paper Mills

Pulp and paper mills have traditionally used a faucet-like pricing approach to procuring pulpwood (paying more when inventory is low and paying less or shutting off suppliers when inventory is high). This approach is proving inadequate because climate issues and other harvesting considerations are making it more difficult to secure supply. One means of addressing this supply issue is to build a larger stockpile during periods of sound harvesting conditions, but practical considerations such as cash flow may prevent this.

Pulp and paper mills sometimes grapple with internal limits aimed at minimizing the capital tied up in inventory. In the absence of such constraints, there are physical limits to the space for storing pulpwood and wood chips on site.

A nimble procurement for supplying pulp and paper mills includes a collection of supply options, drawn on as needed.

Most paper mills in the Northeast sold some or all of their land-based timber supply over the past two decades. Often these sales were subject to long-term supply agreements, guaranteeing minimum annual volumes to the mill or giving them first choice to purchase any pulpwood that is harvested. Some mills retain minor land holdings that they count on for a portion of their pulpwood supply.

Traditional supply areas are generally those closest to the paper mill. This area may or may not have uniform seasonal weather conditions. If the mill is located in an area where the there are fewer annual days of acceptable harvesting conditions, the supply area is extended. Extending the supply area increases the chance of including soils and local weather conditions that allow harvesting when the core supply areas does not. This action often means raising the delivered price of pulpwood or clean wood chips to account for higher trucking costs.

Pulp and paper mills can purchase standing timber and treat it as a reliable portion of supply for the duration of the contract, with terms of one to two years. Forestry staff sometimes purchase this timber from the open market of timber sales available from public and private lands. In other cases, forestry staff from mills use landowner assistance programs to give them the opportunity to purchase timber from assisted landowners. Knowing the volume and harvesting conditions of the standing inventory, the mill can draw on this supply as warranted by demand, weather conditions and landowner goals.

Remote chip yards some distance from the mill are another procurement strategy. These would typically be located in areas without strong local pulpwood demand. Many small suppliers provide roundwood that is chipped before trucking to the paper mill. Such operations can be co-located with compatible, non-competing facilities, such as sawmills or log export yards. Back haul by truckers is taken advantage of whenever possible, though two-way traffic with chip vans is uncommon.

Pulp and paper mills also use remote roundwood concentration yards. These are particularly useful in location where trucking distance to the paper mill is a major impediment to supply from local loggers. Co-location of these yards at facilities already frequented by loggers, such as sawmills and log yards, make them a convenient place to aggregate supply. Loggers who are making deliveries to these facilities can send mixed loads that include both the primary product and pulpwood. Back haul by truckers plays a key role in this. Truck trailers that are capable of hauling both logs and pulpwood make this possible

With a network of remote supply yards in place, a paper mill can then treat them as surge supply capacity through pricing increases if the primary supply area closest to the mill is experiencing decreased production due to soft ground conditions or related weather events. When wood from these locations is not needed, they can simply stop purchasing it. Care must be taken in the timing and logistics of shutting off supply, to assure the suppliers will still be willing to produce when the demand returns.

The start-stop, unpredictable nature of timber harvesting due to climate factors and the impact of this on pulpwood supply has caused some paper mills to focus on expanding their supply of wood chips from sawmills. Sawmills produce wood chips from slabs and edgings as a natural consequence of sawing logs into lumber. Steady and reliable markets for these residual materials are important to these sawmills. Paper mills that have sawlogs to sell on a regular basis, either from company lands or timber purchases, will sometimes use the availability of these logs as leverage to secure mill chip supplies. The paper mill can refuse to sell sawlogs to mills that do not sell them wood chips.

Knowing how and when to draw on each of these paper mill supply possibilities is the art of management. Some of these supply sources are treated as surge capacity. The strategic approach is realizing that climate change has added uncertainty to traditional procurement patterns and logging chance is changing. Expanding procurement channels to the mill that can be adjusted on a real time basis is an adaptation in response to the risk of undersupply.

Climate impacts and other factors that influence wood supply must be viewed in the context of a decline in logging capacity in the region that is being driven by retirements and poor financial results. Paper mills in the Northeast are part of a larger collection of forest industry stakeholders that recognize this. These stakeholders have promoted, encouraged and supported the development of two logger training schools in the region (in New York and Maine) to bring new people into this line of work.

Wood Energy Mills

Pellet mills and facilities that generate energy from wood (for heat or power) have a similar approach to procurement as pulp and paper mills. However, these facilities may require different types and volumes of wood. The slate of procurement options for any one mill is usually a bit narrower than those of paper mills. Electric generators generally use low quality dirty chips made from material that is not suitable for pulpwood. In contrast, pellet mills and wood heating plants need pulpwood quality material that is usually supplied as a clean wood chip. All of these plants types can use sawmill residues for some of their supply.

Wood heating plants have similar considerations in obtaining supply, though they generally use smaller volumes of high-quality wood chips. These plants have the added wrinkle of narrower delivery schedules that do not conflict with uses of the facility, along with quite limited storage capacity in most cases.

All of these plants use sawmill residues for some of their supply. Since some part of every sawlog is converted to burn-quality residuals as part of sawing, feedstock supply from sawmills is tied to the sawmill's ability to obtain logs.

Sawmills

The Northeast is home to a variety of sawmill types, with up to a 4,000-fold difference in their production ranges. These sawmills can be divided in to three general categories - specialty, hardwood and softwood, with a considerable amount of overlap among these types. The sawmills are as diverse as the region's timber supply.

Specialty sawmills make procurement efforts specific to their needs. For example, a white cedar mill in Vermont procures the majority of its supply in the winter because the wet sites where this species grows are typically easiest to access under frozen conditions. With the winter season warmer and less predictable in the past, this mill is at risk of having insufficient supply for its year-round needs. Fortunately, white cedar logs store well for up to two years.

This mill purchases white cedar logs whenever they are available from all suppliers. This means purchasing volumes ranging from pickup truck loads to tractor trailer loads. While the mill has a core of major suppliers, it has a long list of small suppliers that it works to accommodate whenever they have logs available.

Hardwood sawmills procure both sawlogs and timber for their wood supply. Many would prefer to purchase just sawlogs, but that approach provides insufficient certainty of volume, species mix and timing. Sawmills will naturally want to match their production schedules to market demand. Log supply inconsistencies that are tied to seasonal weather variations can make this difficult. Purchasing timber gives them greater reliability in their supplies species mix and quality and some amount of control over the timing of availability.

Purchasing timber can be done directly from landowners or from both public and private land managers. As discussed earlier in the section on harvesting scheduling, contract length for purchased timber has become critical. The shorter contracts of six months to a year that were used in the past are no longer sufficient. Many sawmills believe that a two-year window is necessary to ensure they have sufficient opportunity to complete the harvest.

Timber sale contracts are often extended for opportunities lost to poor weather, but extensions bring complications as well. For landowners that do not sell timber on a regular basis, these extensions can be difficult to understand. tract Extensions sometimes require a further payment to the landowner, which makes securing supply for the mill more expensive.

The main climate related tactic identified in interviews with sawmill procurement staff is assistance with BMP compliance. Since mills are purchasing timber, they often have both in-house or hired excavation crews for cleanup and portable bridges and related structural BMP devices for use in timber harvests. The availability of these resources means that they can be used to help loggers and landowners who are regular suppliers of sawlogs. Similar loans are made of heavy-duty steel pipes for use in corduroy crossings of watercourses.

Procurement foresters for sawmills all report having portable bridges available for suppliers to borrow. Steel bridges are the most versatile and last the longest. Wood bridges wear out and need replacing. Portable bridges are in frequent demand. Everyone who talked about loaning bridges out wanted or planned to acquire more of them to expand this effort.

Providing trucking of logs has been a staple procurement strategy for sawmills for a long time. Many small suppliers do not have their own trucks or do not have enough trucks to meet all their needs. Such loggers may lose potentially productive time after a harvest is complete by keeping a loader tied up on the previous harvesting site while waiting for trucks to become available. Sawmills with self-loading trucks are at an advantage in purchasing logs from these suppliers.

With productive time at a premium in the face of rising costs and decreased harvesting opportunities, anything that helps loggers remain productive is helpful. Providing trucking for sawlogs is one such form of assistance.

Sawmills with in-house trucking sometimes truck additional products for loggers as well. For example, the mill may agree to provide trucking for one load of firewood logs for every load of sawlogs it picks up on a harvesting site. While this trucking is done for a fee, it is a major convenience for a small logging operations that does not have its own trucks.

Sawmills sometimes offer technical assistance to log suppliers. For example, procurement staff may offer help with applications for stream crossing and related permits or with locating boundary lines. While sawmills must ultimately compete on log prices, providing other forms of assistance that are within their power has proven to be an effective way of building long-term supply relationships.

Some sawmills have company-owned land, though seldom enough to supply a large portion of their needs. These lands tend to be used strategically to ensure a supply of logs at times when soft ground conditions or other factors make them unavailable from other sources. The belief is that company-owned lands are better used during periods of climate stress because landowner concerns are not an issue and the mill can accomplish cleanup work at its convenience.

Many sawmills will purchase small tracts of timberland when the opportunity arises. These lands can be held long-term or serve as medium-term holdings to buffer supply.

Conclusions

All types of mills in the Northeast are adjusting procurement practices in the face of new climate realities. Although these adjustments may be subtle and adopted gradually over time, the long-term result is a broad change in the way mills are securing supplies. As in other parts of the supply chain, the main issue for mills is unreliable winter logging seasons, resulting in a less predictable flow of materials.

Adaptations Summary for Wood Procurement
• Pulp and paper mills need a portfolio of supply options to ensure adequate supplies of wood during shoulder seasons and periods of poor logging weather;
• Sawmills require longer timber sale contract terms to ensure enough productive harvesting time is available; and
• BMP, trucking and technical assistance are used as sawmill procurement strategies that address the climate challenges experienced by producers.

Forest Pests and Invasive Species

Forest Pests and Invasive Species

Climate change is linked to the spread of both forest pests and terrestrial invasive species. These threats to forests are recognized by landowners and forests managers, as well as those farther downstream in the supply chain. Some of these pests and invasive species are actively killing important commercial tree species, while others are displacing native species on disturbed sites. Forest workers and active landowners are especially susceptible to tick borne illnesses such as Lyme disease. Threat adaptations have several implications for the forest products supply chain.

Landowners and Forest Managers

Forest pests, some of which are invasive species, are of greatest concern in the near term to forest landowners and managers. Private landowners have altered their harvest scheduling and in some cases their management focus in response.

For example, pre-emptive salvage harvests of ash species have been widespread in areas in or near infestations of the emerald ash borer (EAB). This has been driven largely by the threat of the loss of these trees, but also because landowners fear that quarantines will render the trees valueless. In response, many landowners are harvesting ash trees before they reach financial maturity. Both landowners and forest managers no longer consider ash a crop tree.

Oak wilt has killed or is threatening oak species in many locations in the Northeast. Red oak species are particularly susceptible, while white oak species are more resilient and can live with the disease for several years. It is possible to contain the spread and damage from this pest through early detection and prompt removal. Late detection is more common and often leads to alteration of harvest scheduling to allow salvage harvesting.

Dead oak trees remain commercially viable for sawlogs for some time (white oaks last longer than red oaks). After that they may be suitable only for pulpwood or firewood, as long as they are sound.

Invasive species and pests seem to be of greater concern to public land managers than to private landowners. Private landowners are less likely to have monitoring and control plans for invasive species. Unlike salvage timber harvesting, there is no potential revenue from invasive species control and eradication.

Some consulting foresters report that invasive species and pest control has provided an additional business opportunity for them. This is especially true for those who are certified pesticide applicators. Additional opportunities arise from coordinating and overseeing mechanical eradication efforts.

The breadth and intensity of responsibilities of public agencies in controlling or containing the spread of forest pests and invasive species have increased significantly over the past decade because of climate-related proliferation of these species.

Public natural resource agencies in the Northeast have always been concerned with forest pests and invasive species monitoring and control, which has been part of their responsibilities for the past two decades or so. Climate change has contributed to hastening the spread of both of these concerns. However, added duties do not always come with increased budgets. In many cases, staff time and resources must be diverted from other areas to address forest pest and invasive species.

Monitoring and controlling these nuisances on both public and private land require coordination and collaboration. A general approach includes the following duties.

- Build partnerships and capacity with stakeholders;
- Create frameworks for sharing information;
- Set management priorities;
- Engage and inform the public,
- Prevention and early detection,
- Eradication when possible,
- Promote ecosystem resilience; and
- Evaluate success and share results.

Many of these duties are coordinated through central offices. Field level forestry staff perform both monitoring and control on the lands they manage. Forest pests may be more readily detected on public lands due to the intensity of use and the resulting need for more frequent on-the-ground inspections. Work on control or eradication of terrestrial invasive species is a workload addition.

In the forest products supply chain, actions identified as helping prevent the spread of invasive species include increased monitoring of disturbed areas (such as log landing sites) and requirements in timber sale contracts and road work agreement to wash equipment that might transport invasive species between sites. Contractual conditions of this type require monitoring and enforcement to be effective.

Logging

Logging businesses are most directly impacted by the increased frequency of forest pests and invasive species in the location of their work and the type and size of timber available for harvests. Salvage and pre-emptive salvage often involve removal of smaller trees than might otherwise be harvested.

Some loggers report being required to do equipment washes prior to moving to harvesting sites to help curb the spread of invasive species. While they understand the reason for doing this, they note that it imposes a cost and timing issue in most cases.

Several loggers expressed concern that harvest scheduling in areas that have been heavily impacted by oak wilt has not kept pace with the damage. Beyond the obvious loss of value, loggers observe that working in impacted forest stands in the future will mean the risk of being around many hazard trees.

Wood-Using Mills

All of the wood procurement people interviewed expressed concern over the spread of forest pests and invasive species. There is long-term concern over the future availability of some important commercial species, as well as short term concern about the uptick in supply from salvaged timber. For the most part there has been sufficient market demand to accommodate this supply, especially the large influx of white ash that has been on the market. However, smaller diameter logs are potentially a problem and there will probably be less demand for the smallest size classes during any market downturn.

Timing and contractual requirements imposed by forest managers must be considered by mills in procuring their wood supply. This creates small wrinkles in their plans and procedures for some and significant logistical challenges for others.

Various quarantines have at times made it difficult to move logs from their point of harvest to mills. This is especially a problem when the timber was purchased prior to the quarantine. Larger hardwood lumber companies with multiple sawmills. adjust to this by keeping logs within the quarantined areas, though in some cases this means sending these logs to mills that are farther from their original intended destination.

One large wood energy plant in Vermont was sourcing much of its wood chip supply in nearby New York. When Vermont quarantined ash species entering Vermont from New York, they were faced with the potential loss of some supply and added difficulty in enforcing containment policies. In response, this plant was able to establish that EAB could not survive the wood chipping process if the chipper was producing smaller micro-chips. This plant then gave its largest supplier significant price support as incentive for the purchase and operation of a drum chipper that produced these micro-chips.

Lyme Disease

Nearly everyone who was interviewed expressed concern about the spread of Lyme disease and other tick-borne illnesses. Some had worked with the threat of Lyme disease throughout their careers and other had only experienced this threat recently, as changes in the climate has expanded the range of the deer ticks that spread this disease. Even those who did not have a local threat of Lyme disease were aware that they would be likely to deal with it soon.

Several interviewees among landowners, foresters, loggers and mill staff had first- hand experience with Lyme disease and virtually everyone knew someone who had had it. Those in the highest risk group who regularly work in tick infested areas listed regular precautions they take to minimize this risk. The precautions include wearing paraffin-treated clothing, avoiding working in tick-prone areas during much of the year when ticks are active. Some have obtained medical prescriptions for Doxycycline Hyclate as a preventative measure if they found deer ticks burrowed into their skin.

The expansion of deer ticks and Lyme disease is likely to continue throughout the Northeast. Moving forward, forest workers in areas where this risk has not occurred in the past will need to be more vigilant with preventative measures against the spread of Lyme and seeking prompt treatment if infected.

Conclusions

Changing climatic conditions will inevitably lead to changes in species mix in Northeastern forests. Warmer and wetter conditions may create habitat for invasive species with detrimental effects on commercially valuable tree species. Throughout the supply chain, forest products professionals will continue to face challenges associated with forest pests and invasive species.

Adaptations Summary for Forest Pests & Invasives
• Public land managers dedicate more time and effort to these challenges;
• Pre-emptive salvage and altered forest structure expectations are being practiced on timberlands in the region;
• Invasive species control has become a private sector service for some parts of the supply chain in certain locations;
• Forest workers are practicing awareness, prevention and readiness for Lyme disease and other tick-borne illnesses across expanding areas.

Climate-Related Policy Issues

Climate-Related Policy Issues

Climate-related policy issues were challenging topics in the supply chain interviews and focus group sessions conducted in this study. Public agency staff were reluctant to discuss anything related to policy. Private sector people struggled to identify policy related issues that applied to them without being provided with examples.

Most participants have a grasp on the evolution in local policies related to temporary road closures due to climate impacts. As discussed in the road section, these changes in local policies are not universal around the Northeast. Those who were experiencing early road closures acknowledged that this made their role in the supply chain more difficult.

The primary climate-related public policy discussed in interviews was Renewable Energy Credits (RECs). RECs provide a saleable certificate for the production of renewable energy that displaces the use of fossil fuels. These are particularly important in the forest products supply chain because they make it financially feasible to produce electricity by burning wood chips.

Markets for these low-value wood chips are important for several reasons. These markets allow wood utilization and silvicultural improvements, like the removal of small, low quality trees, that would often be otherwise impossible. For whole tree harvesting operations, these markets afford an additional revenue stream for wood that they must process whether it is used or not.

Even with revenue from RECs, it can be difficult for wood burning electrical plants to compete with natural gas-fueled plants, especially as the price for natural gas drops. For example, despite being eligible for RECs, biomass electric plants in New Hampshire have struggled. Two plants recently closed after the governor vetoed legislation that would have provided additional subsidies for wood energy production. Other plant closures may follow. These closures have ripple effects throughout the Northeast's forest products industry, impacting forest landowners and logging companies in multiple surrounding states.

New York State enacted the Climate Leadership and Community Protection Act in 2019. This law sets ambitious goals for reducing carbon emissions through the use of renewable fuels but fails to include wood in the approved list of renewable energy sources. Rule-making and implementation of this law will take several years, but it seems likely that existing markets for wood as an energy source will be lost.

Conclusions

Awareness of climate policy impacts on the forest products supply chain has been slow to emerge. Recent policy changes provide a few examples of how legislation impacts the industry interests.

It may be necessary for industry and its stakeholders to become better aware of opportunities to identify emergent policy initiatives and strengthen capacity to develop information required by policy makers in order to make informed decisions. The forest products industry would benefit from more widespread knowledge in the policy arena that for wood is a renewable resource.

Adaptations Summary for Climate-Related Policy
• The supply chain takes advantage of any market opportunities provided by policy;
• Silviculture is altered in response to a loss of low-grade markets;
• Equipment investments and production plans by loggers are being altered in response to a loss of low-grade wood markets due to changes in climate-policies; and
• Climate policy initiatives and unintended consequences create uncertainty that make business planning difficult.

Climate Adaptation Summary

Summary

Changes in the climate are having a significant influence on the Northeast's forest products supply chain. The risks in timberland, timber harvesting and primary wood-using mills are evident in the adaptations that are being made in both their infrastructures and practices.

Harvest scheduling has become more complicated for landowners, creating a ripple effect in the supply chain. Landowners need longer scheduling windows to ensure ground conditions, regeneration concerns and market demands are met in a way that accommodates silviculture and remains consistent with sustainability standards. Loggers must balance their work schedule to ensure that they maximize annual productive time. Much like the landowners who need longer scheduling windows, mills require longer timber sale contracts to meet their supply needs.

Best management practices for water quality became widespread in the region even as changes in the climate were occurring. Improvements in structural BMPs have been innovated in response to climate challenges. Excavation equipment on harvesting sites has become a necessity for BMP compliance and maintaining productive uptime under softer or wetter conditions. Advance installations of structural BMPs are often necessary before a harvest begins and regular maintenance may be required to minimize the risk of suspending operations. Behavioral BMPs, such as temporary work stoppages have become a shared responsibility among landowners and loggers, though direct costs associated with this are usually only borne by loggers.

Road maintenance and improvements are necessary to accommodate supply chain demands and climate challenges. Gravel roads need more frequent maintenance and usually require upgrades like larger culverts and improved ditching when they are activated after periods of disuse. Reinforcing and weather-proofing roads with crushed stone key areas has become more common. Loss of winter road building skills and shorter periods of the cold weather necessary to build them has prompted some large landowners to upgrade these roads. These upgraded roads require less skill and time to be ready for use.

Timber harvesting systems have been adopted and adapted in response to climate impacts and threats. Alterations in methods and equipment mixes by whole-tree harvesting loggers have been necessary to operate under climate stresses. The cut-to-length harvesting system has been used in some cases to extend productive time during wet or soft ground conditions. Tree-length systems persist, in part, due to the lower capital investment required and the ability to partially or completely idle under unsuitable ground conditions.

Mills have taken creative steps to procure supply during periods when unsuitable harvesting conditions limit the supply of wood. Pulp and paper mills need a portfolio of supply options to

ensure adequate supplies of wood during shoulder seasons and periods of poor weather. Sawmills require longer timber sale contract terms to ensure enough productive harvesting time is available. BMP, trucking and technical assistance are used as sawmill procurement strategies that address climate concerns experienced by producers.

The spread of forest pests and invasive species has altered harvesting plans, opportunities and forest worker safety throughout the region. Public land managers dedicate more time and effort to these challenges, sometimes at the expense of other stewardship activities. Pre-emptive salvage harvests are being practiced on timberlands in the region, along with revised expectations for the species composition in future forest stands. Invasive species control has become a private sector service for some parts of the supply chain in certain locations. Forest workers are practicing awareness, prevention and readiness for Lyme disease and related tick-borne illnesses across expanding areas.

Climate-related government policies have influenced markets for low-grade wood and are creating uncertainty about the viability of some aspects of the forest products supply chain. The supply chain takes advantage of any market opportunities provided by policy, such as the dirty wood chip markets created by wood-fired electrical plants that rely on renewable energy credits. Silviculture is altered in response to a loss of low-grade markets such as the closure of several of these electrical plants. Equipment investments and production plans by loggers are altered in response to a loss of low-grade wood markets due to changes in climate-policies.

Adaptations in means, methods and behaviors across the Northeast's forest products supply chain demonstrate a resilient response to climate-related risks. Further studies should quantify these factors. Climate-risk support for the forest products supply chain should come in the form of practical technical assistance. A companion report to this publication, the *Northeast Forest products Supply Chain Climate Adaptation Toolkit*, contains recommendations for climate adaptive actions and support activities.

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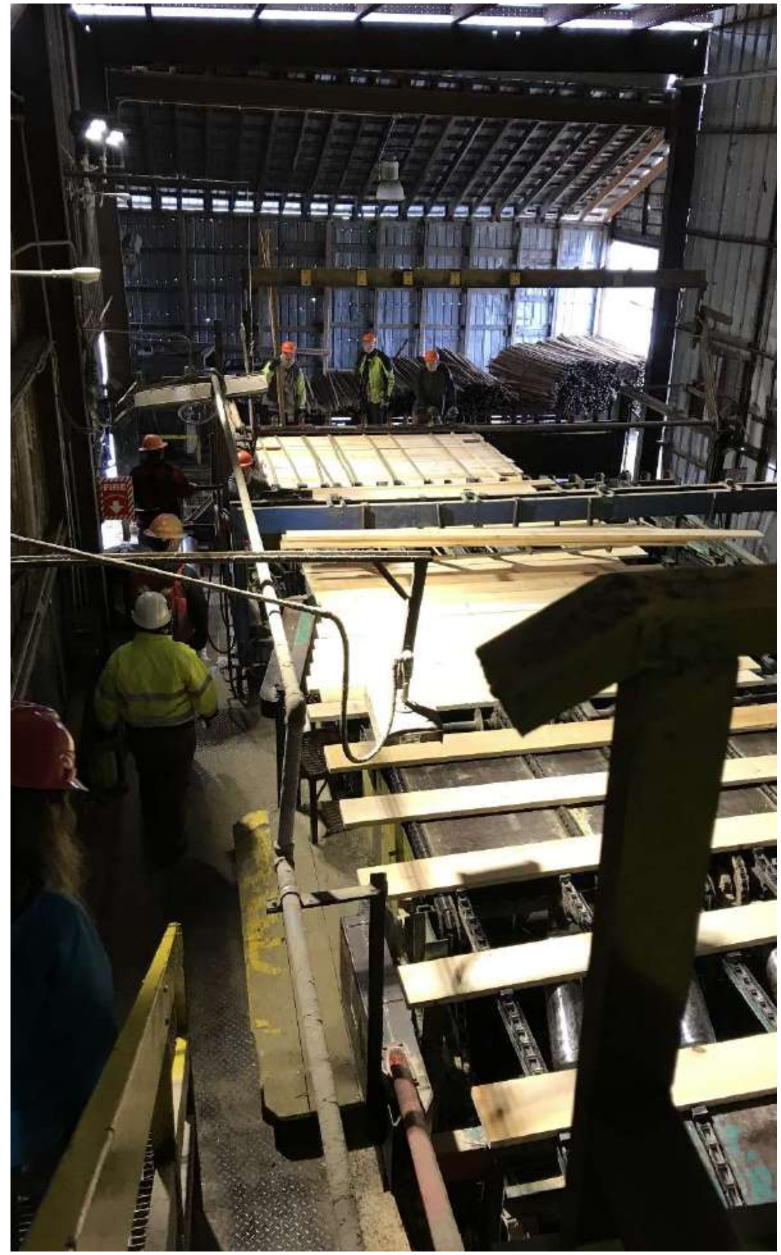


Appendices

Case Study: VT Dept. of Forest, Parks and Recreation

CASE STUDY: Vermont Department of Forest, Parks and Recreation

The following case study includes notes from a conversation illustrating how members of the supply chain are adapting to a changing climate in the course of everyday operations. These notes are supplemented in places with information from the department's website and publications.

The Vermont Department of Forest, Parks and Recreation (FPR) serves all Vermonters in providing stewardship and guidance for the 78% of the state's landscape that is forested. The Department views itself as partner to both the public and private sectors to *"engage in cooperative action to identify and work with these external forces for our collective, mutual benefit so that we create the Vermont we collectively want."* Climate change is among the external forces that FPR identifies, along with international markets and human demand for forest benefits.

FPR's Division of Forestry mission is *"to lead the state in fostering a land ethic that recognizes our responsibility to promote healthy forests and is founded on the principles of respect for the land, sustainable use and exemplary management"*.

A large portion of this mission makes a direct contribution to the forest products supply chain. For example, the division oversees of the current use property tax program for private forestlands, manages state forest lands (including timber sales), provides technical support, enforces and promotes Acceptable Management Practices (AMPs) for protection of water quality in forest operations, monitors and responds to forest pests and diseases, and supports forest products and wood utilization.

A focus group meeting was held with the FPR Forestry Division leadership and key staff members to discuss responses and adaptations to climate change in performing their duties. State staff in attendance included:

- Danielle Fitzko, Director of Forests
- Paul Frederick, Wood Utilization & Wood Energy Program Manager
- Brad Greenough, State Lands Forester, Barre office
- Matt Langlais, County Forester for Caledonia and Essex Counties
- Sam Lincoln, Deputy Commissioner
- Jared Nunery, Orleans County Forester
- Mike Snyder, Commissioner
- Keith Thompson, Private Lands Program Manager
- Peter Walke, Deputy Secretary of Vermont's Agency of Natural Resources
- Dave Wilcox Watershed Forester

The discussion began with overviews about climate policy and how seasonal variation is affecting the forest products industry in the state. Then, agency staff focused in with greater detail on climate change and factors like AMPs, timber sales on state lands, various harvesting systems and pests and invasive species. Summaries of these interactions follows.

FPR and Climate Policy

FPR has important roles in shaping and implementing climate policy. These include ground level practices and goals for state lands, advice for private forest landowners and analysis and input to the state government's legislative processes.

One of FPR's proactive steps on climate change was the production of ***Creating and Maintaining Resilient Forests in Vermont: Adapting Forest to Climate Change*** in 2015. This report was assembled by Commissioner Mike Snyder's Adaptive Silviculture Work Group, with input from many other FPR staff members from around the state.

Danielle Fitzko, notes that the adaptation guide "*made us realize that it's* (adapting to climate change) *part of all of our jobs."*

Asked how this document is shaping the way FPR staff do their jobs, Keith Thompson observed that is it being integrated in an ad hoc way as people figure out what it means in their day-to-day activities:

"I'm not sure we use this as a reference but it's captured some of the thinking that has worked its way into the management that we all do."

Fitzko explains that FPR doesn't frame its work in terms of mitigation or adaptation, but rather a general sense of climate awareness, with the ideas expressed in the adaptation guide informing their work, particularly in managing state forests.

"I think when state lands is talking about management they would train on these concepts and it made them realize that a lot of the things that they are doing are in line. It's calibrated us to have this mindset in what we do", says Fitzko.

The operational aspects of the guide are clearly in practice. For example, forest road maintenance and the replacement of improvements are done to specifications that will withstand storm events that are larger and more extreme than in the past.

Thompson believes state forestry staff are incorporating the adaptive approach for resilient forests from the guide in the silviculture they practice. Staff foresters are now embracing more than just the single tree selection and small group selections that were the focus in the past.

"People are thinking that we've got to support a wider mix of species so let's get larger gaps in places and recruiting more oak and things like that."

Thompson explains that in growing and supporting the growth of forests in the state FPR plays a large role in climate mitigation. Having state and private forests in Vermont and fulfilling the role of stewarding them well provides a solid foundation for further action.

"Adapting the forest and making sure it continues to have that role in the face of climate change is really the way we've been looking at it, getting us most of the way there. There is definitely some additionality that we build in there but there are so many things

we need from forests that I think a lot of folks are saying carbon is a big part of it but let's not throw out all this other stuff for the sake of it."

Fitzko acknowledges the important role her department must play in addressing climate change:

"We are trying to rebuild our efforts around climate change."

Towards this end, FPR is planning to add a staff member dedicated to climate issues.

Sam Lincoln sees climate issues as important in terms of policy development within the department. It has become a consideration in nearly every initiative. He believes that state legislators are starting to recognize that they must create the space necessary for the players in the forest products supply chain to adapt to changing conditions.

Peter Walke is not only the Deputy Secretary of Vermont's Agency of Natural Resources but was appointed by the Governor to be the co-chair of the Vermont Climate Action Commission. He is quick to acknowledge that FPR is currently doing the most important climate work pursued by the State of Vermont.

Seasonal Changes

FPR staff throughout the state have first-hand experience with the effects of seasonal changes on forest management. Of particular concern were warmer and wetter conditions, and a shorter time window when frozen ground permits access to forest stands.

Brad Greenough from FPR's Barre office notes that it's rare to get winter logging conditions in December in recent years. He points out that a reliable starting date for winter conditions is difficult to pin down.

"On state sites", says Greenough, *"we have control of the land so if conditions are not correct we won't allow the logger to go in."*

One private lands the starting dates for winter logging have less reliable oversight. Greenough explains the implications of this reality:

"On state lands we won't allow them to start until conditions are right, a landowner might allow that or not know any better or a logger might be really desperate to start working because they haven't worked for a few weeks or months and they are willing to take the chance and do the cleanup at the end."

For state timber sales requiring frozen ground conditions there is less certainty that a logger will have access in any given year. For timber that is already under contract, this means holding up the harvest until conditions are correct, even if the buyer has paid in advance.

Matt Langlais observes a lot of timber sales in private lands in his role as a county forester. He notes that the lines between good logging conditions and starting points have become blurred:

"It's a little bit hard to differentiate between good logging conditions and when it's appropriate to start. What I see more and more is a recognition that there is a cost to bring the site back into compliance after it's done, so folks are starting when they shouldn't be, when it's costing them more, when they have to bring excavators in behind them, to restore the site."

It seems that in some winters, some areas may never achieve suitable ground conditions. Keith Thompson observes that portions of the state – such as Chittenden County and other areas close to Lake Champlain, have open or abbreviated winters, with little snow cover and milder temperatures. .

Greenough adds that mid-winter rain events have become increasingly common. These events interrupt or should interrupt logging.

Greenough shared that loggers and mills that purchase timber on state lands have adapted to the department's expectations:

"They are getting a lot better about policing themselves. Communication is better and they won't just go and work without telling you, whereas in the past they wouldn't stop unless you told them to."

Paul Frederick observes seasonal climate adaptations among Vermont's forest products community. He sees the unpredictability of winter weather causing adjustments by mills in building up their wood inventory in the winter:

"You tend to get boom and bust. Guys will raise prices to try to get more wood in the yard then there is a big freeze up and all of a sudden, in two weeks you've got a full yard."

This strategy works, for now, Frederick says, because *"the capacity is out there to move a lot of wood in a short amount of time, if conditions are right."*

Frederick adds something that is becoming common throughout the Northern Forest region:

"Towns are posting roads in the middle of the winter now."

Posting roads limits the amount of weight that may be trucked on them, effectively ruling out moving forest products. Several FPR employees noted, however, that cooperation with local road superintendents can lead to a compromise that allows limited trucking under cold conditions, usually early in the morning.

Spring weather and ground conditions in Vermont pose the same sort of challenges to harvest scheduling, logging and wood procurement as they do in other areas. Seasonal conditions usually limit FPR's ability to accomplish things on state lands, but they view spring as a good time to promote protection and responsible activities within the supply chain.

Keith Thompson offers several insightful observations about spring challenges to FPR's mission.

"One of the things I have wrestled with, when we define our mission by implementing good silviculture and demonstrating best management practices or maintaining compliance, spring is a threat to that part of our mission. On the other hand, part of our mission is also maintaining the health of the forest products industry and I have been asked by logger – why aren't you highlighting shoulder season harvests and putting those up - and so, from that side of it, identifying those places where the lowest risk occurs and putting those jobs out and creating those opportunities. I don't see us prioritizing this and I don't see a lot of consultants prioritizing this because they are risk averse."

Thompson believes there is a lot of room for improvement in shoulder-season harvest scheduling. Loggers coming off a poor winter season might naturally look to spring to make up for it, even if ground conditions are not ideal.

Dave Wilcox points out that, for loggers, *"spring is an important part of the year in terms of AMP emphasis."* Spring is when soft wet ground conditions collide with logging businesses eager to start covering their costs and mills needing wood to keep producing (further discussion of this issues takes place in the next section).

The wet ground conditions of the spring are increasingly extending into the summer months. Over the past decade, the month of June experiences 1.4" more of precipitation in Vermont than it did in the 1980's.

Brad Greenough says that wet ground conditions do not pose as much of a problem on state land timber sales, because they simply don't allow logging under those conditions. He explains:

"We generally don't have a lot of summer jobs in our district. Generally, if conditions are good, when it's dry, we allow them to start."

On sites that are predominantly wet, FPR does not schedule summer bare ground harvests, requiring frozen winter conditions instead.

On the other hand, most FPR staff acknowledge that high standards on state lands might put more pressure to harvest from private lands that aren't under such strict regulation. They add that there is a need for improvement in recognizing how management of state lands affects privately owned working forests.

Brad Greenough observes a lot less logging occurring on private land in his district in the in the summer now than in the past. Summer conditions today are just too unreliable.

Dave Wilcox believes that summer logging now follows a start-stop pattern, depending on soil type, much like spring and fall does. This pattern causes additional AMP considerations:

"In terms of AMP education and practices, summer is important, with the weather. If everything is froze up in the winter and it rains - even it if rains for a week - it's not that big a deal, but if you are

logging in the summer and you are not doing the necessary practices in between, if you are not buttoning up your sale if you know it's going to rain, or putting in bridges that don't allow enough to pass through, there are problems. It's important in terms of educating people and training, what the summer logging conditions are beforehand."

Wilcox explains that even good summer conditions have some important limitations to keep in mind:

"Summer logging, silviculturally, you have to be careful too, because trees don't like to be bumped in the summer, before the end of August. You can have a load of logs come in with no bark on them. That's fine a for a log but it's not fine for trees in the woods. If you are doing patch cuts or a shelterwood or some lower density residual stand that's one thing but if you are really working in a tight stand, summer might not be the best time."

Year-round, warmer and wetter conditions are impacting forest practices in Vermont. FPR is working to adapt to these seasonal changes. These adaptations could provide a model for other state agencies.

Acceptable Management Practices

As discussed in the previous section, an important aspect of the changes in seasonal conditions and their impact on forest practices is the impact on water quality. In Vermont , Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont were first introduced in 1987. These AMP standards have been adopted as rules for Vermont's water quality statutes. Adherence to AMPs are voluntary in many cases but are a requirement on private lands enrolled in Vermont's current use property tax program.

Vermont AMPs focus on structures and practices in much the same way as BMPs do in neighboring states. Structures are easy to design, build and promote. Behavioral practices are important and noticed and emphasized as well and play a key role in getting good results. The costs of behaviors such as suspending logging operations to protect water quality are harder to quantify and can be easy to overlook by for those who do not bear them.

Keith Thompson believes that we aren't far past the *"who will pay for them?"* stage of integrating AMPs into timber harvesting work.

FPR Deputy Commissioner Sam Lincoln believes that it's a question of *"rewarding good behavior versus rewarding bad behavior."* Rewards generally come in the form of continued work and the sort of confidence in loggers that allows them to continue working with the knowledge that they will take the appropriate actions to protect water quality. Those whose action do not inspire confidence are more likely to have operations suspended until conditions improve.

Dave Wilcox oversees FPR's AMP program statewide. He offered that AMP complaints tend to come from those timber harvests with less forester supervision.

Wilcox has noticed there are some recurring problem loggers in terms of AMP compliance. Violations are most likely to occur when the weather isn't suitable. When loggers have trees down and ready to skid they feel pressure to get them out. This pressure might come from mills that have purchased the timber or from their own financial situation. Other times it's a question of loggers producing when they should not, just because they are far enough away from a main road that they believe no one will notice.

Violations can occur even under otherwise good conditions, if the right precautions aren't taken. According to Brad Greenough, sunny days with muddy streams are a good indicator when this is the case.

Thompson explains:

"When somebody is operating when they shouldn't that's a problem that will manifest itself on the skid roads. It's ugly, soil moves, but sometimes you can put it back. Where we really see the challenges that oftentimes are really independent of weather are stream crossings. It's less about is it raining and more about the stream crossing being too small and loggers just not doing the work that should have been done in the first place."

FPR was a national leader in adopting water quality standards for timber harvesting and providing training and technical assistance decades ahead of other states in the region. The FPR staff's understanding of water quality issues in scheduling harvests, harvesting practices and supplying mills allows them to detect and understand the stresses that changes in seasonal weather patterns impose on the forest products supply chain.

State Timber Sales

According to Brad Greenough, timber sales on state lands follow a relatively standard seasonal pattern. Forestry staff spend the summer and bare-ground shoulder seasons marking and preparing timber sales. Harvesting takes place in winter, during which time forestry staff focuses on sale supervision.

State timber sales that are prepared in the summer are usually sold in the fall. The uncertainty of the winter season has led FPR to offer two-year contracts. Knowing that they will have more than one winter to complete the harvest lessens the risk to bidders on timber sale. Many timber sales simply require more time. *"Most of the big sales take a couple of winters,"* according to Paul Frederick.

One climate vulnerability the FPR recognizes in the state sale process is that after the harvesting is done, it's often "t*oo wet to close out complete timber sales until mid to later summer*", according to Frederick.

Greenough notes that loggers are the buyers of timber sales in his district, far more often than sawmills. He attributes this to the high volume of pulpwood on state sales – often 1,000-1,500 cords. High pulpwood volumes make sales less attractive to sawmills.

Greenough notices that large logging operations that need to maximize annual production will pay up to four times the going pulpwood stumpage rate to secure the job. He believes the high costs of owning large mechanized logging operations requires these operations to secure a nearly continuous flow of work. This reality prompts the high bids the state has seen for low-grade timber.

While Vermont currently has no preferred or high performing logger reward system in its bidding process, special requirements in timber sales are one method of ensuring only qualified contractors will submit bids, according to Paul Frederick.

Overall state timber sales in Vermont are continuing to follow historic seasonal patterns, with most planning activities in the spring, summer and fall, and most harvest operations occurring in winter. A number of adaptations have been necessary, including longer timber sale contracts and greater understanding of the time and conditions needed to conclude harvests and meet contractual obligations.

Observations on Timber Harvesting Systems

Timber harvesting systems used in Vermont have changed over time to accommodate the type of harvests available and the quality of timber in these harvests. Equally important to these considerations are the ground conditions for harvesting. Changes in the climate present more challenging ground condition. Adaptations in both logging equipment and methods are evident to the FPR staff.

Whole-tree harvesting systems are the dominant method in many portions of Vermont. These whole-tree systems provide the opportunity to chips tree limbs and tops for an added revenue stream, those wood chips are a low value product. This opportunity presents a trade-off that must be considered.

Matt Langlais says that *"the foresters have learned that putting up chips costs production."* In such cases, they are finding a better use of the tree tops than chips is in shoring up wet trails to increase the skidder flotation. Says Langlais:

"I have one forester up here whose practice is to find the nearest place he can put a patch cut, to the landing. The logger goes in, cuts as much out of that patch cut as he can and puts the brush in the main trail from there, before he starts doing any tending work or work for the maintenance of the forest, just to get that brush in place for skidding purposes."

Grapple skidders are an essential part of any whole-tree harvesting system. These machines collect whole tree stems and pull them to the landing site. Some loggers on larger tracts of timberland have adopted larger six-wheeled grapple skidders because they pull larger bunches of trees and ultimately use less fuel than four-wheeled grapple skidders.

Dave Wilcox does not like the size of six-wheeled machines. He believes they require too much operating room for use in smaller woodlots or in stands dominated by high quality residual stands that must be protected from damage.

Sam Lincoln points out that many central Vermont forest landowners do not want skid trails full of brush. This practice that works so well for skidding whole trees makes skid trails very difficult to walk on afterwards.

Sentiments opposed to larger scale logging operations, shared by many, are part of the reason for the rise to cut-to-length (CTL) systems all over Vermont. An added feature has been the ability of CTL systems, under the right circumstances, to remain in production when soil moisture conditions might rule out skidding.

Dave Wilcox believes that a CTL harvester gives the logger greater control of the rate of harvest because they can adjust their activities based on conditions.

“If they see a big enough 2-week window, they go lay the wood down, if they are a little unsure they will cut less wood.”

Jared Nunery notes that the initial enthusiasm over CTL systems in his area (Orleans County) is over. CTL systems persist with a few loggers who have found a good niche for them.

Matt Langlais in neighboring Essex and Caledonia Counties agrees. He believes that early adopters of CTL systems were promised increased production prices for their work by large landowners. These price increases never materialized and the lower production rates took their toll. Many of the original CTL loggers have gone back to higher production whole tree harvesting systems.

Keith Thompson, with statewide responsibilities, has observed there is a niche for CTL, but the system isn’t universally well-suited to the Vermont landscape. He notices a learning curve in CTL operation. There are unanticipated costs in building trails for forwarding that surprise some loggers new to the system.

Nunery sees the CTL niche in practice. Those that are still operating in his area have found foresters who will place them on the correct job types. These loggers know how to emphasize the performance of their equipment. *“The people that did commit are fully committed and are doing well”* he says.

Regardless of the type of harvesting system being used, Dave Wilcox prefers to see a piece of excavation equipment on each job site. Softer and wetter ground conditions must often be addressed mid-harvest. As noted throughout this report, this practice is increasingly common in the northeast as an adaptation to changes in the climate.

Vermont’s experiences with climate change influence on ground-based timber harvesting systems mirrors that of the region. Small, tree-length systems with hand felling persist, in part because it less costly to idle them when ground conditions are uncooperative. The more capital intensive WTH systems are a good response to timber quality and harvesting needs, but the high capital costs require creative support to ensure they operate as much as possible. CTL systems have some potential to gain productive time under soft ground conditions but are expensive and are not universally well-suited Vermont's terrain.

Invasive Species, Plants and Pests

Climate not only affects forest practices but is also resulting in observable changes in species make up, including a proliferation invasive plants and pests. It can be useful to focus climate discussions around invasive species, according to Mike Snyder, who frequently addresses legislators and citizens groups on the topics of forestry and climate. He notes:

"I'm having reason to say this more and more – I say invasive species, plants and pests. I think they are all having an impact and they are all exacerbated, to one degree or another, by climate change. So, it's an opportunity to talk about the others too and not just the plants."

Addressing the increasing frequency of forest pests and invasive species associated with climate change have become a regular part of FPR's work.

FPR is definitely reacting to pests, says Danielle Fitzko. Emerald ash borer (EAB) is the most recent pest to gain a foothold in Vermont and has rapidly become a prime concern. She notes that forest tent caterpillar is a recurring, cyclical concern and that they are watching for oak wilt which has plagued nearby states.

Sam Lincoln talked to landowners and loggers who have altered their schedules to address EAB risk. At this time, EAB reaction on state lands hasn't changed harvesting priorities, in part because of the low proportion of ash on state lands, comprising just over 5% of the net volume of trees in the state.

Deer ticks and the threat of Lyme disease are an important concern among the FPR staff and everyone working in Vermont's forests. Keith Thompson says that approximately one third of FPR's foresters have dealt with Lyme disease. Sam Lincoln mentions three loggers he knows that have been incapacitated to the point of being unable to work due to Lyme disease. Matt Langlais alters his work schedule to minimize risk of exposure to deer ticks by scheduling current use property inspections in towns known for high tick populations during the lower risk portions of the year.

Invasive species are a concern that FPR struggles to address in much the same way as landowners and agencies in other states. Paul Frederick explains that invasive species can be hard to detect when they are present at a low level that is still easy to control. Detection is far easier after these species become established and more difficult to remove.

Individual Vermont forest district offices are doing some treatment of invasive species on state lands. Physical control and removal are time consuming and must compete with other priorities for staff time. One control method associated with state land timber sales and other work by outside contractors is the physical inspection of equipment before it enters state land.

Keith Thompson states that private landowners are increasingly aware of invasive species on their property. Some would like to control or remove them. Cost-share funding from the USDA Natural Resources Conservation Service has made this possible in some cases. Invasive species control on private lands in Vermont is rare in the absence of this funding.

Each of the northeastern states is experiencing similar challenges when it comes to forest pests and invasive species. The differences in these challenges seems to be in timing and intensity. Vermont is in a position to learn from other states in some instances and to provide experienced based technical assistance to neighboring states on others.

Conclusions from FPR Interactions

Vermont has embraced a suite of adjustments to adapt to warmer and wetter conditions and other climate-related changes. In many cases, adjustments are adopted gradually, until they become standard practice.

For example, logging companies in Vermont have excavation equipment on hand for site clean up to protect water quality. This ensures both compliance and continued operation. Also, FPR now usually gives a multi-year time frame for timber sales, so that loggers and mills have more options to operate under suitable weather conditions.

Vermont continues to be proactive in environmental protection. In 1987, Vermont was an early adopter of AMPs to protect water quality. And, in 2015, the FPR's Adaptive Silviculture Work Group produced a climate guide, *Creating and Maintaining Resilient Forests in Vermont: Adapting to Climate Change* – (fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/The_Forest_Ecosystem/Library/Climate%20change%20report_final_v6-18-15a.pdf).

Climate change is having similar impacts on forests and the working landscape of Vermont as in other states. FPR work in this area provides a model for adjusting to those impacts.

Case Study: Watershed Agricultural Council

CASE STUDY: Watershed Agricultural Council Forestry Program

The following case study includes notes from a conversation illustrating how members of the supply chain are adapting to a changing climate in the course of everyday operations. These notes are supplemented in places with information from the program's website and publications.

The Watershed Agricultural Council (WAC) is a non-profit organization that protects New York City's drinking water by supporting the working landscape within the Catskill-region watershed that supplies the system's reservoirs. WAC focuses on sound forestry and agricultural practices to protect water quality, as well as supporting the economic viability of the small businesses that keep the rural landscape undeveloped.

WAC's Forestry Program has five facets, including:

- Forest management planning;
- Forest management practices and best management practices (BMP) implementation;
- Education of landowners, loggers and foresters;
- Research and demonstration, and
- Acquisition and oversight of conservation easements on forestland.

The Forestry Program's professional staff includes a director, three watershed foresters, a watershed educator, an outreach specialist and a research and evaluation forester. A diagram excerpted from WAC's *2019 Forestry Program Handbook* outlining these purposes is shown in Figure 1.

WAC's work involves climate change adaptations in a number of ways. In particular, their work with BMP implementation incorporates many approaches that help to protect water quality, while still allowing loggers to work in spite of warmer and wetter conditions. WAC's work also involves conservation easements, invasive species management, and policy advice, all of which have climate implications. A focus group meeting was held with most of the program's staff to discuss these issues. A summary of the discussions that arose in this meeting follows.

Best Management Practices

WAC's latest Forestry Program Handbook describes their BMP program this way:

> *The purpose of the Best Management Practice Program is to provide financial and technical assistance to Loggers, Foresters and Landowners in order to support the implementation of Best Management Practices on privately owned forestland within the New York City Watershed.*

Forestry Program Director Tom Pavlesich make's WAC's goals in this area clear – *"keeping water quality protected and keeping loggers viable."*

Pavlesich' s emphasis on these compatible goals is borne out in WAC's promotion and support for best management practices. WAC is able to provide cost-share funding to loggers for projects like erosion control and portable bridge installation. . There is no comparable program anywhere else in the Northeast. Cost sharing by WAC has been in place for over 25 years.

Veteran logger Paul Krickhahn Sr. is sold on this program, so much so that he is not interested in harvesting timber outside the watershed where the incentives are not available. He believes BMP compliance expectations are the same on many properties outside the watershed, but the cost of compliance falls squarely upon him. The combination of financial support, rapport and respect from WAC's forestry program staff makes for a pleasant work experience.

WAC has developed a solid working relationship with many loggers like Paul Krickhahn. WAC Watershed Forester Karl VonBerg has been with the program for much of its existence and acknowledges that building trust in the logging community has taken time:

"We have a category of loggers who just do everything right. They really care about it. Then we've got – I call it the messy middle, where, well, if they've got time, they are going to do stuff that's nice. Then you've got the ones, where, that's just a hopeless case and aren't even going to try."

Pavlesich expanded on this idea:

"There have been guys, and it's just a very few, that you can't even work with them. They just don't have the mindset. They're not concerned about our priorities. But that's very few."

Best Management Practices are voluntary. WAC foresters are keenly aware of this and work with the knowledge that there are times when it's convenient for landowners, loggers and mills to ignore them and keep producing – working in times and areas that should be off limits.

The WAC forestry staff all acknowledge the seasonal changes in climate they have witnessed over time and were quick to share their insight on how these changes have affected BMP implementation in the watershed.

Perhaps the biggest change has been in winter. Karl VonBerg points out that they don't have a winter logging season in the same sense that it occurs in more northerly areas:

"Basically, we have year-round mud season. You try to figure out how to work windows of time."

In the past winter was considered a time of low BMP concern in their program, as frozen conditions protected both soil and water, not to mention logging productivity. That has changed and now they have year-round concerns that require monitoring and increased focus on erosion control and other of structural BMPs.

The Forestry Program staff generally acknowledge that the increased intensity of storm events that is typically associated with climate change. VonBerg shared a difference he has noted over his long history in the greater watershed area:

"When you get a two to three inch rain events that's different than when you got, over the month, one quarter inch at the beginning of the week, then you got half an inch, that's a lot easier to dry up than a three inch rain event."

Tom Pavlesich's observation about these conditions cuts right to the heart of their impact on the forest products supply chain:

"The only choice you have is to stop working."

Pavlesich goes on to point out that loggers and WAC foresters use as many tools and techniques as possible to avoid shut down. The need to work has spurred innovative practices and opportunities for WAC to provide technical assistance to help solve water quality problems.

When loggers have to stop working, the entire supply chain is impacted. Scheduled harvests take longer, meaning that subsequent harvests might have to be rescheduled or delayed in ways that push them into the shoulder seasons, when ground conditions are less ideal. Mills struggle to meet the supply quotas necessary for their own production schedules.

VonBerg is one of several people in the region who notices a forward shift in winter's annual occurrence. He believes that the winter logging season, when and where there is one, starts later in January and last longer into March. Despite this, he believes that loggers are never truly able to make up the lost December and January time.

VonBerg's comment about *"year-round mud season"* rings true in the shift that has occurred from the traditional start of spring mud season in mid-March to a shorter variable window that is difficult to identify or predict. One prominent logger in the Catskill watershed observed that he is sometimes able to start working very early in the spring after the initial drying occurs, working quite a bit in April, only to be shut down again when ground conditions become wet in May.

This start-stop pattern of logging work makes it difficult to own and operate newer and more expensive equipment. VonBerg's favorite loggers are those who are small and diverse, meaning they can harvest timber when conditions are right and pursue other work and business interests when logging conditions are poor.

The WAC Forestry Program's approach and administration of BMP cost-sharing has evolved over time, adapting to changing seasonal considerations and emphasizing the practices that are proven to work best. Current cost-sharing for structural BMPs can amount to thousands of dollars in cash payments, along with significant valuable technical assistance. Tom Pavlesich points out that most payments are re-imbursements, but they have the flexibility to provide funding in advance for certain practices:

"When we are cost sharing BMPs, gravel is a big up-front cost, so we can do partial payment. Usually we wait until the job is done

until we make the final payment, but we can cut a check for gravel right off the bat, so the logger is not going to carry the cost."

The increased use of gravel to facilitate timber harvesting by overcoming a lack of frozen or dry conditions is a widespread climate adaptation in the logging community. Most loggers recognize situations when the cost of lost production outweighs the costs of a few well-placed loads of gravel , even when covering the up-front gravel cost is daunting. The flexibility to provide advance funding for suitable projects is a great example of a different sort of climate adaptation by WAC itself.

WAC Forestry Outreach Specialist Heather Hilson points out that many winter logging cleanups take place after the job is over. Sometimes this is months later. About 80% of the BMP projects WAC cost shares happen in the third quarter – July to October. Often winter cleanups must wait until then for ground conditions to dry up enough for work to be done. This is especially challenging for small crews that might have to give up productive harvesting time to take care of the clean-up work.

Karl VonBerg has been promoting the idea of putting water bars in place at the start of winter jobs so that after the ground freezes, protection is built in for the thaws. This sort of thinking is a natural consequence of a long-standing program that does regular follow up monitoring and long-term research.

WAC has learned that the proper implementation of BMPs involves more than putting erosion control structures in place and hoping for the best or being satisfied that an effort has been made. Tom Pavlesich notes that in working with loggers, they may make multiple site visits to consult on problem areas. When they can identify and isolate critical situations, they swarm around them. Says Pavlesich:

"We actually will cost-share the same water bar four or five times in really bad situations – in a riparian zone, where the trail can't be anywhere else. That's what you have to do, from our perspective."

The WAC approach is one of focusing the most effort and resources on the situations that can have the best positive impact in pursuit of their goals. This universal lesson applies to BMPs, climate adaptation and a host of other endeavors.

In logging operations throughout the northeast, having a bulldozer or an excavator on site has become a nearly universal requirement. This is driven by both a desire to comply with best management practices and the very practical need to support harvesting practices by addressing soil moisture concerns. Karl VonBerg notes that in the Catskills, loggers have been quick to see the benefit of this adaptation:

"Commonly most crews around here cut and bunch with a dozer."

Logging in the watershed region is typically done with ground-based tree length systems. This is a process of hand felling and limbing in the woods with a chainsaw, followed by bunching and skidding limbed-out tree stems with a cable skidder. Skidding tends to be the limiting factor when ground conditions are too wet. Bunching with the bulldozer allows productive progress, even on days when skidding is not possible. The added benefit is the bulldozer availability to address direct BMP concerns. Loggers without a bulldozer must incur moving and hiring costs each time one is needed, making it tempting to forego smaller BMP compliance items.

WAC's cost-share program goes a long way towards ensuring BMPs are implemented in the New York City watershed. Other regions and states could learn from this model, however, it clearly depends on funding to cover costs. Another benefit of the WAC model is dedicated staff that put thoughtful effort into assisting the forest products industry. WAC staff has innovative ideas about BMPs and recognize some of the true costs of protecting water quality that have been overlooked by others. A discussion of these ideas follows.

Structural vs. Behavioral BMPs

There is more to the successful implementation of best management practices than putting the right structures in place at the right time. Some combinations of weather and ground conditions are not suitable for working, regardless of how many erosion control devices are in place. As winter weather has become softer and precipitation greater in previously drier summer months, conditions may become unworkable mid-job, especially for skidding. Suspending work or some aspects of it is a best management in and of itself and is often far more costly than installing erosion control devices or a temporary bridge.

Tom Pavlesich is one of a handful of foresters in the Northeast who recognize this situation. He makes a distinction between structures and behavior in logging and BMP implementation:

"When you look at the BMP manual, there are structural BMPs, but there's a lot of behavioral BMPs and the opportunity costs associated with those go uncompensated. I feel like in winter, especially, if you have frozen ground, great, but if you get a thaw the ground is still not in a condition to be worked with structural BMPs, so your behavioral BMPs are the go-to. So, it's actually a double whammy where loggers are doing things that don't get compensated more often in that period of time."

In other words, structural BMPs are things like proper installation of bridges or using gravel for erosion control. These types of actions are eligible for cost-sharing programs with WAC. In contrast, behavioral BMPs include suspending work when ground conditions are unsuitable. Not only is no cost-share available for this type of BMP, but the logger stands to lose money by keeping equipment idle. This important, distinction is in BMP compliance is rarely recognized.

BMP compliance has grown and spread, even as the costs of logging equipment, labor and other inputs have increased. Many in the logging sector have mastered structural BMPs but feel financial pressure to work and produce as many days as possible. Milder winters and increased soil moisture in much of the year mean that fewer working days with suitable ground conditions are available. This stresses both the financial health of the business and water quality.

Communication and relationships between loggers and foresters are an important part of successful timber harvests. A solid working relationship between the two means defining success to include a combination of silvicultural requirements, financially beneficial transactions for all parties, and the protection of water quality in the face of growing climate challenges.

Heather Hilson points out that some foresters don't take the time to develop respectful relationships with loggers and then wonder why they get poor results. Often it is just not bothering to understand the timber harvesting system requirements and financial realities. Some foresters disregard logger input on on-site harvesting restrictions and requirements.

Tom Pavlesich notes the importance of understanding the perspective of the loggers they partner with in protecting water quality. He characterizes it this way:

"The trick is that you are dealing with businesses and businesses generate profit, or attempt to, so you have to communicate in that language. That's what cost sharing is."

This understanding has fostered an important insight that Pavlesich shares with others in describing their program:

"From our standpoint, the viability of individual harvesting jobs is important. We are cost-sharing stuff, but we only cost-share the structural stuff, not the behavioral stuff."

The WAC forestry program is proof that a non-traditional approach to forestry issues can yield sustainable results. Pavlesich believes that moving beyond traditional models by public agencies has the potential for further improvements throughout the region. He notes, for example, that the US Forest Service and various state and regional government agencies focus on assisting landowners. Broadening this focus to assisting practitioners such as loggers has the potential for more tangible and immediate results. He shares this observation:

"In our boots, working to protect water quality, you have to work right with the logger."

"Working right with the logger" and engaging them with cost-share funding, technical advice and training opportunities has helped the program embrace the notion that sustaining the watershed's working landscape depends on the financial success of people who depend on it for their livelihood. The WAC forestry staff interacts with the larger forestry community in the Northeast and find it frustrating that the idea of cooperative interaction with loggers is not more widely embraced. They believe that looking beyond structural BMPs and including recognition and support for the financial

consequences of behavioral would be a positive move in building these relationships.

Conservation Easements

WAC has an active conservation easement program. They have acquired conservation easements on about 30,000 acres, 20,000 of which are on forestland. The Forestry Program oversee the timber harvesting requirements on these properties. A timber harvest plan is required before any logging can take place. WAC also supports this requirement with cost-share funding.

The *"focus on what's important"* approach typifies the Forestry Program's efforts. Pavlesich points out that *"we only condition extraction of the timber."* This allows them to *"hyper-focus"* on their goal of protecting water quality, without devoting staff and resources to non-water quality issue. While water quality issues have always been important in logging, climate change impacts that further limit logging opportunities make this focus on timber extraction within these conservation easements especially important.

Forest Pests, Diseases and Invasive Species

The increases in the number of forest pests and invasive species commonly associated with climate change are evident throughout the Catskill watershed.

The emerald ash borer's impact here has been similar to that in other areas in New York State, with many trees dying and widespread pre-emptive salvage of ash sawtimber by landowners. Often this means harvesting smaller ash trees that would have been left as crop trees in the past. Harvests of this type result in significantly lower productivity for tree-length logging crews.

Hemlock woolly adelgid is a concern because, as Tom Pavlesich says, because hemlock *"it's not a commercial species, it's a water quality species."* Hemlock typically grows in streamside management zones where heavy vegetative cover can protect stream banks from erosion and provide the shade necessary for many native aquatic species.

The Forestry Program staff believe there is an increase in the number and frequency of invasive species in the forest, though they see the high elevations within their region as providing as partial check to their spread. They believe that equipment washing between harvesting site moves will probably be necessary in the future to curtail the spread of these species.

Control of invasive species is listed as a potentially important goal of forest landowners in WAC's Forest Management Plan advice. Their Management Assistance Program supports the removal of invasive species with significant cost-share payments that can amount to over $200 per acre.

Deer ticks and the risk of Lyme disease are a commonly accepted risk in the working landscape here, even if they were unheard of when some of the staff first started their careers.

WAC Forestry Program Policy Advice

A wide-ranging group discussion with the WAC Forestry Staff resulted in several important policy suggestions, observations and concerns about the long-term viability of the forest products supply chain. Most of these thoughts were articulated by Program Director Tom Pavlesich.

Pavlesich sees the direct impact of climate change on the forest products supply chain as more challenging harvesting conditions. This problem impacts scheduling, harvesting and procurement of timber by mills. From his perspective, it's obvious how the costs involving these challenges are being addressed:

"We are asking the landowner to deal with climate effects in regard to their timber resource. They pass that off to the mill – they just want my wood, it's their job. The mill takes that responsibility and guess what they do with it? They pass it off to the logger. It's rolling down the hill and the logger is the one that is absorbing all of the costs."

Climate change is one more test of a working landscape that must regularly confront other challenges. Taking on this challenge will be easier if institutions and the various links in the supply chain work together. Tom Pavlesich expresses this sentiment this way:

"The problems associated with climate change are challenging and involve a lot of different people and I don't think we stand a chance of addressing those problems without a strong level of trust and that all starts with empathy and the ability to understand what the other person is going through and what they are confronting and dealing with. If we're not trying to understand each other, that foundation, that trust, a lot of this doesn't matter."

Tom sees bringing the people in the working forest landscape together in productive respectful relationships as one step in this process. With a better sense of unity established, he sees an outside vulnerability that must be addressed:

"There is the real world and there is perception and I think public perception of logging as harmful to forests could put us in a vulnerable spot. I think as we confront climate change that casting the forest products industry as a partner is important. We need people with experience in the woods to create the forest that is resilient, so if we can place loggers and foresters as the environmental professionals that they are, filling this niche, as the people we need to do a better job of all this."

If the public better understands the niche of these environmental professionals, Pavlesich sees the forest products supply chain as having the potential and the ability to take on many of the challenges climate change poses to our forests:

"The increased focus on forest resilience in the face of climate change could be an opportunity, because I think one of the biggest threats to our forest from climate change is just the innate nature of our forests, the lack of regeneration, the lack of structure in our forest. So I feel like that could be an opportunity, where our forests and loggers in particular could be the mechanism we use to create diversity, to create the structure we need to be resilient and that may permit, down the line, cost-share programs to establish patch cuts or group selections that create this structure."

Conclusion

In many ways WAC provides a model for climate change adaptation for other regions and states. By providing support at many levels – for landowners, foresters, and loggers – they create strong partnerships and a stronger forest products industry.

Clearly, cost-share programs help with BMP implementation. Even though WAC's cost-share programs only cover structural BMPs, the fact that WAC staff acknowledges the existence and importance of behavioral BMPs is an important advancement. Moving forward, WAC and others will have to address the profit loss associated with behavioral BMPs if there is an expectation for loggers to fully implement these environmental protections.

WAC also uses its conservation easement program to work towards climate adaptation and environmental protection, and they play a leading role in management of invasive species in New York forests. Although WAC continues to strive to improve its existing programs, other states could learn from the systems that they have in place.

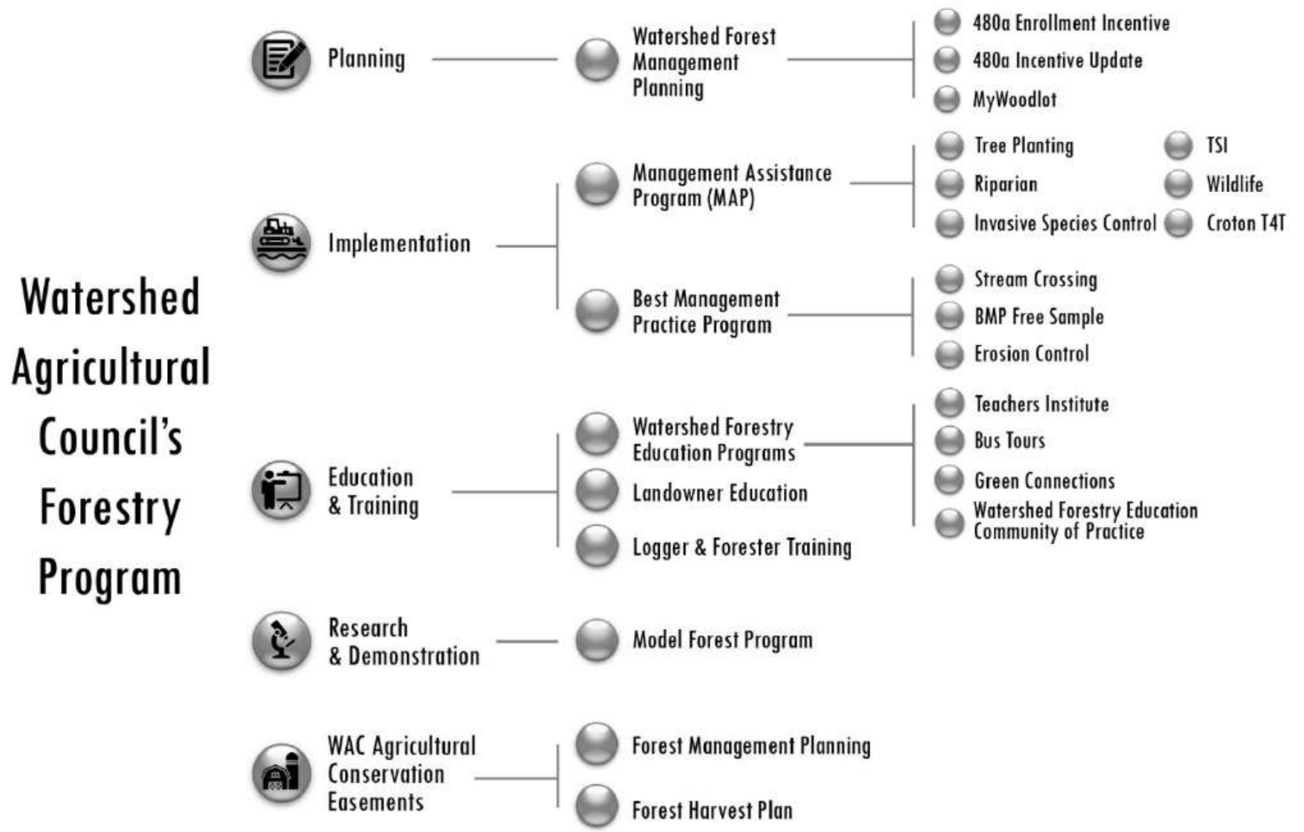
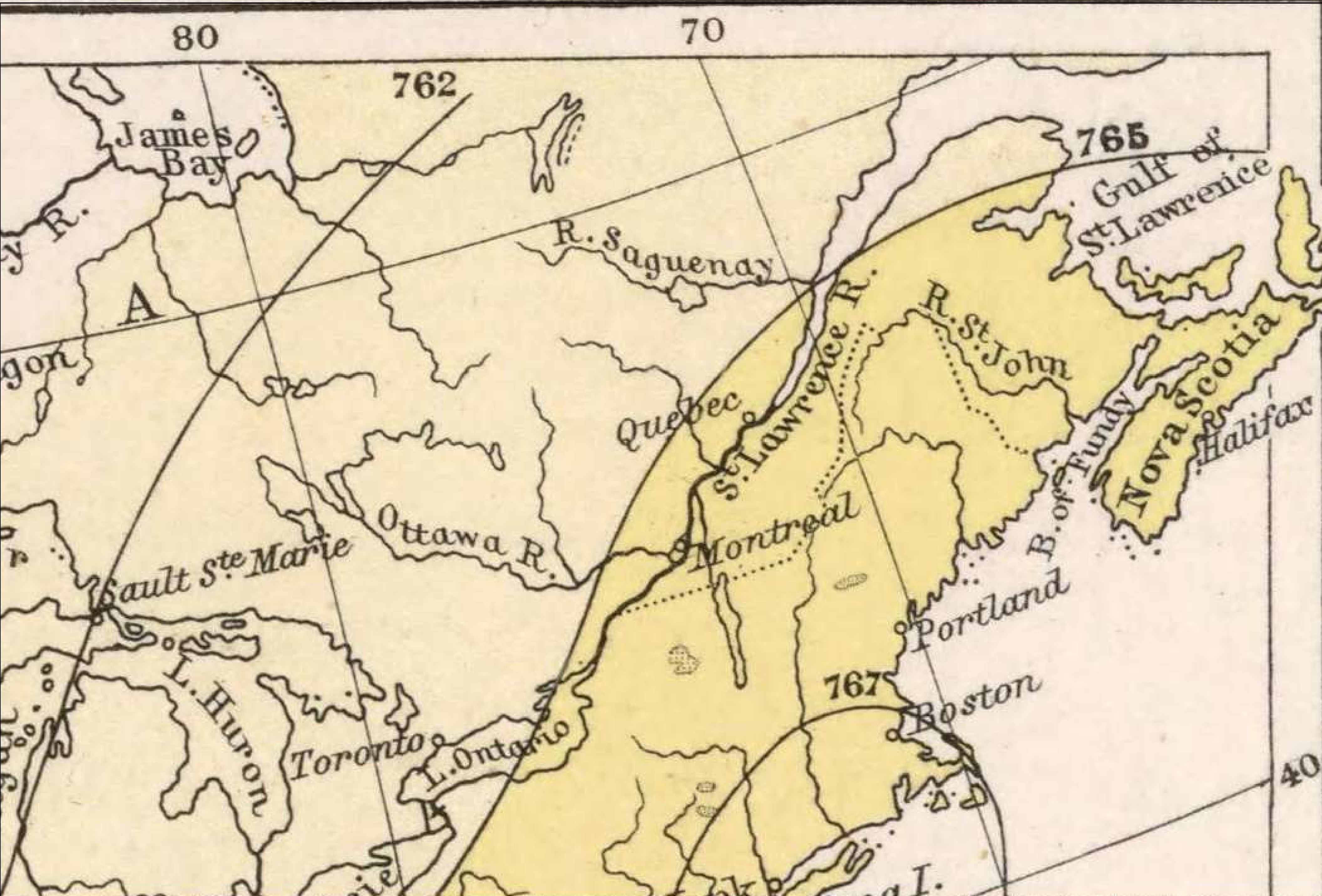


Figure 1. Watershed Agricultural Council Forestry Program's detailed purposes.

Figure 1. Watershed Agricultural Council



County-level Temperature and Precipitation Comparisons

Table A-1. Increase (decrease) in average monthly temperature (°F) for Connecticut counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fairfield	3.0	0.8	0.9	1.3	2.0	1.8	2.7	1.9	3.5	3.7	0.8	4.5
Hartford	3.3	0.7	0.8	1.0	1.7	1.3	2.2	1.7	3.6	3.6	0.6	4.3
Litchfield	3.4	1.0	0.9	0.9	1.9	1.4	2.4	1.5	3.4	3.5	0.8	4.7
Middlesex	2.9	0.7	0.9	1.3	1.7	1.5	2.5	2.0	3.7	4.0	0.7	4.4
New Haven	2.7	0.5	0.7	1.3	1.8	1.6	2.6	1.9	3.5	3.8	0.7	4.4
New London	3.5	1.0	1.0	1.5	1.8	1.7	2.6	1.9	3.3	3.7	0.9	4.9
Tolland	3.8	1.0	0.9	1.2	1.8	1.5	2.3	1.9	3.4	3.5	1.0	4.9
Windham	3.7	0.8	0.8	1.4	1.8	1.5	2.3	1.6	3.2	3.4	0.9	5.0

Table A-2. Increase (decrease) in average monthly temperature (°F) for Massachusetts counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barnstable	3.5	1.6	1.0	1.9	2.1	1.2	2.7	2.3	3.1	3.7	1.1	4.5
Berkshire	3.3	1.2	0.9	0.7	2.0	1.7	2.0	1.3	3.2	3.4	0.9	4.6
Bristol	3.2	0.8	0.6	1.8	2.1	1.4	2.6	2.1	3.3	3.5	0.8	4.5
Dukes	3.5	2.0	1.0	1.5	1.8	0.9	2.5	2.2	3.2	3.8	1.2	4.4
Essex	3.2	0.7	0.6	1.9	1.6	1.2	2.0	1.8	3.4	3.2	0.9	4.2
Franklin	3.7	1.1	0.9	0.8	1.9	1.6	2.1	1.7	3.5	3.4	0.7	4.9
Hampden	3.5	0.9	0.7	0.8	1.6	1.1	2.1	1.5	3.3	3.3	0.7	4.5
Hampshire	3.4	1.1	0.7	0.6	1.5	1.1	1.8	1.4	3.2	3.2	0.8	4.5
Middlesex	3.6	0.7	0.6	1.8	2.0	1.7	2.4	2.1	3.5	3.4	1.0	4.4
Nantucket	3.7	2.1	1.3	1.8	2.0	1.2	2.4	2.2	3.1	3.7	1.5	4.5
Norfolk	3.4	0.8	0.7	2.1	2.1	1.7	2.7	2.4	3.5	3.4	0.9	4.6
Plymouth	3.3	0.9	0.7	2.1	2.2	1.4	2.6	2.2	3.3	3.6	0.7	4.5
Suffolk	3.6	1.0	0.9	2.5	2.2	1.8	2.8	2.7	3.5	3.5	1.2	4.7
Worcester	3.7	1.0	0.8	1.4	2.0	1.8	2.6	2.0	3.7	3.5	0.9	4.9

Massachusetts

Table A-3. Increase (decrease) in average monthlytemperature (°F) for Maine counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Androscroggin	3.5	0.4	0.5	0.5	1.4	1.1	1.8	1.9	3.5	3.4	0.9	4.1
Aroostook	4.2	0.1	0.8	-1.0	0.7	0.6	1.9	2.2	3.4	2.6	1.7	4.6
Cumberland	3.2	0.0	0.0	0.6	1.4	1.2	1.9	1.8	3.3	3.3	0.4	3.7
Franklin	4.0	0.3	0.6	-0.7	1.1	0.7	1.6	1.8	3.4	3.1	1.1	4.4
Hancock	4.2	0.4	0.8	0.3	0.5	0.0	1.8	2.0	3.1	2.7	0.6	4.0
Kennebec	4.0	0.8	0.7	0.4	1.1	0.7	1.7	2.1	3.5	3.4	1.1	4.2
Knox	3.2	0.0	0.0	0.4	0.7	0.5	1.8	2.0	3.2	2.7	0.5	3.6
Lincoln	3.5	0.4	0.4	0.6	1.1	0.8	1.9	2.1	3.5	3.1	0.8	3.8
Oxford	3.9	0.5	0.5	-0.1	1.3	0.8	1.5	1.7	3.3	3.3	1.1	4.7
Penobscot	4.4	0.0	0.9	-0.2	0.5	0.3	1.8	2.1	3.5	3.1	1.1	4.6
Piscataquis	4.2	0.0	0.8	-0.7	0.8	0.6	1.8	2.0	3.5	2.9	1.6	4.8
Sagadahoc	3.7	0.5	0.5	0.6	1.4	1.2	2.1	2.1	3.6	3.5	1.0	4.1
Somerset	4.0	0.2	0.9	-0.8	1.1	0.7	1.9	2.0	3.6	3.1	1.4	4.5
Waldo	3.7	0.3	0.4	0.4	0.9	0.4	2.0	2.4	3.5	3.2	0.8	4.0
Washington	4.6	0.8	1.6	0.2	0.3	0.2	1.8	1.8	3.4	2.9	0.9	4.9
York	2.9	0.1	-0.1	0.5	1.0	0.8	1.6	1.6	3.1	2.9	0.5	3.6

Table A-4. Increase (decrease) in average monthly temperature (°F) for New Hampshire counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Carroll	3.5	0.4	0.4	0.1	1.8	0.9	1.4	1.4	3.3	3.1	0.7	4.4
Coos	3.9	1.2	0.3	-0.7	1.8	0.9	1.5	2.0	3.7	3.5	1.5	5.3
Grafton	3.7	1.1	0.4	-0.1	1.8	1.0	1.5	1.7	3.4	3.3	1.1	4.9
Belknap	3.6	0.4	0.3	0.5	1.3	1.3	1.9	1.8	3.3	3.2	0.8	4.2
Cheshire	3.8	1.2	1.0	1.0	1.7	1.7	2.1	2.1	4.1	3.7	0.8	5.1
Hillsborough	3.7	0.9	0.6	1.4	1.8	1.8	2.1	2.0	3.7	3.4	1.0	4.5
Merrimack	3.7	0.7	0.5	1.0	1.7	1.6	2.1	2.1	3.7	3.4	0.8	4.5
Rockingham	3.2	0.4	0.3	1.4	1.5	1.4	2.1	2.1	3.7	3.2	0.9	4.2
Strafford	2.7	0.0	-0.1	0.9	1.3	1.0	1.8	1.9	3.4	2.9	0.6	3.9
Sullivan	3.7	1.1	0.5	0.6	1.9	1.6	2.1	2.1	3.9	3.7	0.9	4.8

Table A-5. Increase (decrease) in average monthly temperature (°F) for New York counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albany	3.3	1.0	0.6	0.3	1.9	1.1	1.4	1.1	3.2	3.4	0.6	4.6
Allegany	1.7	1.1	0.6	0.7	3.2	1.8	1.1	1.1	2.5	2.6	0.2	4.2
Bronx	3.3	1.6	1.3	1.9	1.9	1.8	2.6	1.9	3.1	3.5	1.0	4.7
Broome	2.3	0.8	0.8	0.0	0.0	2.1	1.2	1.4	0.6	2.6	2.7	0.3
Cattaraugus	1.7	0.6	0.4	0.3	2.9	1.5	0.9	0.8	2.6	2.4	-0.1	4.1
Cayuga	2.0	0.9	0.1	-0.5	2.1	1.1	0.7	0.7	2.3	2.7	0.4	3.8
Chautauqua	1.3	0.5	0.3	0.3	2.7	1.4	0.8	0.9	2.1	2.3	-0.2	3.8
Chemung	1.7	0.6	0.4	0.3	2.8	2.0	1.7	1.2	3.1	3.0	0.2	4.4
Chenango	2.6	1.0	0.1	-0.2	2.2	1.2	1.5	1.0	3.1	3.2	0.5	4.6
Clinton	3.0	0.6	0.7	-0.5	2.8	1.2	1.3	2.3	3.7	3.3	1.4	4.0
Columbia	3.5	1.2	1.0	0.9	2.1	1.4	1.9	1.3	3.5	3.7	0.8	4.8
Cortland	2.1	0.9	0.0	-0.4	2.1	0.9	1.2	0.7	2.6	2.9	0.4	4.0
Delaware	2.9	0.8	0.1	0.4	2.2	1.1	1.6	0.9	3.2	3.2	0.3	4.3
Dutchess	3.8	1.4	1.3	1.4	2.2	1.9	2.5	1.7	3.5	3.8	1.1	5.1
Erie	1.9	0.7	0.5	0.4	2.8	2.0	1.1	1.5	2.9	3.0	0.6	4.0
Essex	3.3	1.1	0.3	-0.2	2.4	1.2	1.6	2.0	3.4	3.0	1.0	4.9
Franklin	3.5	1.6	0.8	-0.4	2.5	1.2	1.2	2.1	3.6	3.2	1.5	4.9
Fulton	3.3	1.1	0.5	0.1	2.3	1.0	1.4	1.1	3.2	2.9	0.9	4.7
Genesee	1.6	0.7	0.7	0.2	2.8	1.8	1.2	1.6	3.0	3.0	0.8	4.0
Greene	3.1	1.1	0.6	0.7	1.8	0.9	1.5	0.8	3.1	3.4	0.4	4.5
Hamilton	3.3	1.4	0.3	-0.5	2.5	1.1	1.2	1.4	3.5	3.0	1.0	5.3
Herkimer	2.9	0.9	0.1	-0.6	2.9	1.5	1.5	1.5	3.5	2.9	0.8	4.8
Jefferson	3.1	1.2	0.6	-0.6	2.2	1.8	1.4	2.0	3.3	3.2	1.1	4.5
Kings	3.1	1.4	1.2	2.0	1.7	1.7	2.6	1.9	3.0	3.3	0.8	4.6

Table A-5 (continued). Increase (decrease) in average monthly temperature (°F) for New York counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lewis	3.0	0.9	0.1	-0.7	2.2	1.5	1.4	1.7	3.2	3.0	0.9	4.5
Livingston	1.7	0.9	0.8	0.4	3.1	1.7	1.1	1.3	2.7	2.9	0.5	4.0
Madison	2.7	1.2	0.0	-0.5	2.1	1.1	1.4	1.1	3.1	3.1	0.7	4.4
Monroe	2.2	1.1	1.0	0.3	2.9	2.0	1.3	1.6	3.0	3.0	0.9	4.1
Montgomery	2.7	0.9	0.2	0.1	2.0	1.1	1.4	1.0	3.1	2.8	0.6	4.2
Nassau	3.0	1.4	1.4	1.8	1.9	1.7	2.7	2.0	3.1	3.3	0.6	4.2
New York City	3.3	1.5	1.3	1.3	2.0	1.8	1.8	2.5	1.9	3.1	3.5	1.0
Niagara	1.6	0.4	0.6	0.3	2.5	2.2	1.2	1.7	3.0	3.0	1.0	3.9
Oneida	3.1	1.0	0.1	-0.6	2.6	1.3	1.5	1.4	3.4	3.1	0.9	4.4
Onondaga	2.4	1.1	0.2	-0.5	2.1	1.2	1.2	1.2	2.7	3.0	0.6	4.0
Ontario	1.7	0.7	0.4	0.1	2.4	1.4	0.8	1.1	2.4	2.7	0.4	3.6
Orange	3.0	0.9	0.5	1.3	2.1	1.8	2.2	1.5	3.2	3.4	0.6	4.7
Orleans	1.6	0.6	0.7	0.1	2.6	1.8	1.2	1.5	2.9	2.8	0.9	4.1
Oswego	2.8	1.2	0.5	-0.4	2.5	1.5	1.3	1.5	2.9	3.0	0.9	4.2
Otsego	2.3	0.8	0.0	0.1	2.3	1.3	1.5	1.0	3.0	3.0	0.2	4.1
Putnam	3.2	1.2	1.0	1.5	1.8	1.8	2.4	1.7	3.3	3.7	0.8	4.8
Queens	3.0	1.4	1.1	1.7	1.8	1.7	2.6	1.9	3.0	3.3	0.8	4.4
Rensselaer	3.6	1.3	1.0	0.3	2.2	1.7	1.8	1.7	3.6	3.6	0.8	4.9
Richmond	3.5	1.6	1.4	2.4	1.9	1.8	2.6	1.9	3.2	3.3	0.8	4.8
Rockland	3.2	1.3	1.1	1.6	1.9	1.6	2.3	1.7	3.2	3.5	0.8	4.7
St. Lawrence	3.4	1.2	0.6	-0.6	2.7	1.7	1.0	1.9	3.4	3.2	1.2	4.6
Saratoga	4.0	1.7	1.0	0.3	2.2	1.2	1.7	1.6	3.4	3.5	1.2	5.4
Schenectady	3.3	1.3	0.5	0.2	2.0	1.2	1.6	1.3	3.2	3.2	0.9	4.7
Schoharie	2.3	0.8	-0.1	0.2	1.8	0.6	1.2	0.7	2.7	2.8	0.1	3.9

Table A-5 (continued). Increase (decrease) in average monthly temperature (°F) for New York counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Schuyler	1.7	0.6	0.2	0.1	2.8	1.9	1.5	1.2	2.9	2.7	0.3	4.1
Seneca	1.7	0.6	-0.1	-0.5	2.1	1.0	0.6	0.7	2.2	2.5	0.2	3.6
Steuben	1.6	0.6	0.3	0.5	3.0	1.9	1.4	1.1	2.6	2.6	0.1	4.1
Suffolk	3.1	1.2	1.3	1.7	1.8	1.4	2.4	1.7	3.1	3.7	1.0	4.6
Sullivan	3.0	0.5	0.4	0.9	1.8	1.6	1.9	1.0	3.1	3.2	0.8	4.4
Tioga	1.8	0.8	0.0	0.0	2.3	1.5	1.5	0.5	2.6	2.6	0.3	4.1
Tompkins	1.5	0.7	-0.2	-0.3	2.3	1.3	1.3	0.6	2.5	2.8	0.1	3.8
Ulster	3.1	1.2	1.0	1.2	2.1	1.7	2.0	1.3	3.1	3.1	0.7	4.5
Warren	3.7	1.8	0.7	-0.1	2.3	1.1	1.5	1.7	3.3	3.2	1.2	5.5
Washington	3.9	1.5	1.0	0.0	2.5	1.5	2.0	2.1	3.5	3.7	1.1	5.4
Wayne	1.7	0.5	0.2	-0.2	2.1	1.5	0.6	0.9	2.3	2.4	0.4	3.5
Westchester	3.4	1.4	1.3	1.6	1.9	1.8	2.5	1.9	3.4	3.7	1.0	4.9
Wyoming	1.5	0.7	0.6	0.3	3.0	1.6	1.1	1.4	2.7	2.9	0.5	4.0
Yates	1.7	0.7	0.4	0.1	2.7	1.6	1.1	1.2	2.5	2.6	0.4	3.7

Table A-6. Increase (decrease) in average monthly temperature (°F) for Rhode Island counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bristol	3.2	0.8	0.9	1.8	2.0	1.3	2.5	2.1	3.2	3.6	1.1	4.5
Kent	3.3	0.9	1.1	1.8	2.2	1.5	2.4	2.0	3.1	3.7	1.1	4.8
Newport	3.1	0.9	0.8	1.7	2.0	1.0	2.3	2.0	3.0	3.7	1.3	4.4
Providence	3.4	0.8	0.9	1.7	2.0	1.6	2.3	1.9	3.3	3.5	1.0	4.9
Washington	3.3	1.0	1.1	1.6	2.0	1.4	2.4	1.8	3.1	3.7	1.1	4.7

Table A-7. Increase (decrease) in average monthly temperature (°F) for Vermont counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Addison	3.8	1.4	0.4	-0.6	1.2	0.9	1.4	2.0	3.5	3.1	1.3	5.1
Bennington	3.8	1.2	0.8	0.0	1.9	1.7	2.0	1.8	3.6	3.7	0.7	4.8
Caledonia	3.4	0.9	-0.2	-1.1	1.4	0.5	0.8	1.3	2.8	2.8	0.7	4.7
Chittenden	3.8	1.3	0.8	-0.1	2.9	1.6	1.8	2.5	4.1	3.5	1.5	4.9
Essex	3.9	1.4	0.1	-0.8	1.8	1.1	1.7	2.0	3.6	3.5	1.5	5.4
Franklin	3.7	1.0	0.7	-0.3	2.7	1.4	1.8	2.6	4.0	3.6	1.6	4.8
Grand Isle	3.5	1.0	0.8	-0.4	2.7	1.5	1.7	2.5	3.6	3.6	1.2	4.2
Lamoille	3.4	0.8	0.2	-0.6	2.4	1.1	1.4	2.3	4.0	3.4	1.4	5.0
Orange	4.0	1.3	0.4	-0.3	1.9	1.1	1.4	1.7	3.3	3.1	1.0	5.0
Orleans	3.6	1.2	0.1	-1.0	1.9	1.0	1.3	2.2	3.5	3.4	1.5	5.2
Rutland	3.5	1.4	0.4	-0.3	1.4	1.3	1.7	2.0	3.8	3.3	1.1	5.1
Washington	3.5	1.1	0.2	-0.6	2.0	0.9	1.2	1.6	3.3	3.1	1.0	4.7
Winham	3.5	1.0	0.8	0.2	1.4	1.3	1.7	1.6	3.6	3.5	0.4	4.7
Windsor	3.8	1.2	0.5	0.1	1.8	1.4	1.7	2.0	3.8	3.5	0.9	5.1

Table A-8. Increase (decrease) in average monthly precipitation (") for Connecticut counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fairfield	0.1	0.3	-0.3	-1.3	-0.7	0.2	-0.2	0.8	0.7	0.1	-1.6	1.1
Hartford	0.5	0.0	-0.3	-0.9	-0.9	0.0	-0.4	1.2	0.7	0.7	-1.5	1.3
Litchfield	0.4	-0.1	-0.5	-1.2	-0.7	0.0	-0.4	1.1	0.8	0.9	-1.4	1.4
Middlesex	0.1	-0.2	-0.6	-1.3	-0.9	0.0	-0.9	0.7	0.5	-0.1	-1.9	0.8
New Haven	0.0	0.1	-0.7	-1.4	-0.8	-0.1	-0.7	0.7	0.7	-0.1	-1.8	1.0
New London	0.0	-0.2	-0.3	-1.0	-0.4	-0.2	-1.1	0.2	0.9	0.5	-2.1	0.8
Tolland	0.4	-0.2	-0.2	-0.7	-0.5	0.1	-0.6	1.6	1.0	0.6	-1.7	1.1
Windham	0.5	0.0	0.0	-0.8	-0.4	-0.1	-0.9	1.2	1.0	0.9	-1.8	1.0

Connecticut

Table A-9. Increase (decrease) in average monthly precipitation (") for Massachusetts counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barnstable	0.8	0.7	0.3	-0.5	0.5	-0.2	-0.5	-0.3	1.0	1.5	-0.5	0.9
Berkshire	0.9	-0.2	-0.7	-0.9	-0.5	0.4	-0.4	1.2	1.3	0.8	-1.4	1.1
Bristol	0.8	0.4	0.6	-0.5	0.0	0.0	-0.4	-0.1	0.9	1.5	-0.9	1.2
Dukes	1.0	1.2	0.2	-0.4	0.7	-0.6	-0.7	-0.6	1.2	1.8	-0.5	1.3
Essex	0.4	0.1	0.2	-0.9	-0.5	0.4	-0.8	1.0	0.1	1.4	-1.6	1.2
Franklin	0.6	-0.3	-0.5	-0.9	-0.6	0.7	-0.3	1.6	1.0	1.3	-1.4	1.4
Hampden	0.5	-0.1	-0.3	-0.9	-0.8	0.4	-0.5	1.4	0.8	0.8	-1.5	1.5
Hampshire	0.5	-0.2	-0.4	-1.0	-0.8	0.6	-0.3	1.7	0.9	1.0	-1.4	1.4
Middlesex	0.4	0.3	0.2	-0.7	-0.4	0.1	-0.6	0.9	0.5	1.5	-1.5	1.2
Nantucket	0.8	0.9	0.0	-0.3	0.5	-0.2	-1.0	-0.4	0.9	1.4	-0.2	0.8
Norfolk	0.8	0.2	0.5	-0.5	0.0	0.0	-0.9	0.6	0.6	1.6	-1.4	1.1
Plymouth	1.0	0.4	0.7	-0.6	0.2	-0.1	-0.4	-0.1	0.9	1.6	-0.8	1.0
Suffolk	0.7	0.2	0.5	-0.5	-0.1	0.1	-0.7	0.4	0.5	1.4	-1.4	1.3
Worcester	0.5	0.1	0.1	-0.8	-0.5	0.1	-0.6	1.3	0.8	1.4	-1.5	1.3

Table A-10. Increase (decrease) in average monthly precipitation (") for Maine counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Androscroggin	0.6	0.4	-0.5	-0.5	-0.4	1.2	-0.1	0.9	0.6	1.9	-1.5	1.4
Aroostook	0.5	0.7	0.4	0.6	0.3	1.3	-0.1	-0.4	0.2	1.5	-0.8	1.3
Cumberland	0.5	0.5	-0.3	-0.6	-0.5	1.0	-0.2	0.8	0.7	1.7	-1.6	1.5
Franklin	0.6	0.4	-0.2	-0.1	0.2	1.1	0.1	0.4	-0.2	2.3	-1.3	1.9
Hancock	0.9	0.2	-0.6	-0.2	0.0	1.1	-0.9	0.0	-0.1	2.4	-1.2	1.8
Kennebec	0.9	0.5	-0.3	-0.4	-0.5	1.1	-0.2	0.6	0.6	1.9	-1.0	1.5
Knox	1.4	0.9	-0.2	-0.5	-0.5	1.6	-0.5	0.3	0.7	2.4	-1.0	1.7
Lincoln	0.9	0.7	-0.2	-0.6	-0.5	1.6	-0.3	0.5	0.8	2.1	-1.2	1.4
Oxford	0.6	0.3	-0.1	-0.1	0.2	1.1	0.3	0.5	0.0	1.9	-1.3	1.8
Penobscot	0.6	0.3	-0.1	-0.1	-0.2	1.0	-0.8	-0.2	0.0	1.8	-1.1	1.6
Piscataquis	0.7	0.4	0.3	0.1	0.2	1.2	-0.2	0.2	-0.2	1.8	-1.0	1.8
Sagadahoc	0.7	0.6	-0.3	-0.6	-0.6	1.5	-0.3	0.4	0.7	2.2	-1.5	1.3
Somerset	0.7	0.5	0.1	0.2	0.3	1.2	0.3	0.3	-0.2	1.9	-1.1	1.7
Waldo	1.4	0.5	-0.3	-0.6	-0.5	1.1	-0.5	0.1	0.2	2.2	-1.0	1.8
Washington	0.8	0.4	-0.3	0.2	0.0	1.0	-0.1	-0.5	-0.1	2.6	-0.8	2.1
York	0.6	0.4	0.1	-0.8	-0.9	0.8	-0.4	0.5	0.6	1.5	-1.7	1.5

Maine

Table A-11. Increase (decrease) in average monthly precipitation (") for New Hampshire counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Carroll	0.6	-0.1	-0.2	-0.5	-0.4	1.0	0.5	0.9	0.5	1.9	-1.1	1.6
Coos	0.7	0.4	0.0	0.6	0.5	1.1	0.2	-0.2	-0.1	1.5	-1.6	1.5
Grafton	0.7	-0.1	-0.3	0.1	0.0	1.0	0.9	0.3	-0.1	1.6	-1.5	1.5
Belknap	0.6	0.2	0.0	-0.5	-0.3	0.4	0.5	0.9	0.9	1.6	-0.9	1.7
Cheshire	0.5	0.0	-0.3	-0.7	-0.5	0.7	0.0	1.8	1.4	1.8	-1.3	1.4
Hillsborough	0.3	0.1	-0.1	-0.9	-0.6	0.2	-0.5	1.3	1.0	1.8	-1.4	1.3
Merrimack	0.5	0.1	-0.1	-0.5	-0.4	0.3	0.0	1.0	0.7	1.8	-1.2	1.5
Rockingham	0.4	0.3	0.4	-0.9	-0.6	0.2	-0.8	1.0	0.7	1.3	-1.5	1.3
Strafford	0.3	0.3	0.1	-1.0	-0.9	0.4	-0.5	0.6	0.6	1.2	-1.7	1.4
Sullivan	0.6	-0.1	-0.3	-0.2	-0.3	0.8	0.4	0.7	0.3	1.9	-1.2	1.5

New Hampshire

Table A-12. Increase (decrease) in average monthly precipitation (") for New York counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Albany	0.6	0.5	-0.3	-0.4	-0.1	0.6	0.2	1.6	1.0	1.4	-1.0	1.2
Allegany	1.1	0.5	-0.2	0.6	0.6	-0.7	0.3	0.4	0.4	1.9	-0.5	1.2
Bronx	0.4	0.5	0.1	-1.5	-0.2	0.5	-0.8	1.5	0.3	0.1	-1.1	1.4
Broome	1.0	0.4	0.2	0.3	0.7	0.7	0.7	2.3	1.3	1.4	-0.6	0.8
Cattaraugus	1.3	0.7	-0.2	0.7	0.7	-0.7	0.4	0.3	0.3	1.5	-0.6	1.2
Cayuga	0.9	0.7	0.2	0.5	0.6	0.4	0.5	0.8	-0.3	1.7	1.7	-0.6
Chautauqua	1.0	0.8	-0.3	0.6	0.3	-0.4	-0.3	-0.5	-0.1	1.0	-1.0	0.7
Chemung	0.7	0.0	-0.3	0.3	0.2	-0.6	0.1	0.9	1.6	1.8	-1.0	0.6
Chenango	0.9	0.5	0.2	0.6	0.7	0.9	1.2	1.8	0.5	1.6	-0.6	0.9
Clinton	0.5	0.6	0.5	0.8	0.8	2.1	0.0	-0.6	-0.3	1.3	-1.3	0.6
Columbia	0.6	0.1	-0.5	-0.7	-0.5	0.5	-0.5	1.7	1.2	1.0	-1.0	1.0
Cortland	0.9	0.5	0.0	0.3	0.5	0.5	0.4	1.3	0.4	1.4	-0.8	0.9
Delaware	0.9	0.4	0.1	0.2	0.2	0.8	0.8	1.8	1.1	1.7	-0.8	1.1
Dutchess	0.3	0.0	-0.5	-1.1	-0.8	0.2	-0.3	2.0	1.0	0.7	-1.0	1.1
Erie	0.9	0.5	-0.1	1.1	0.3	-0.2	0.3	-0.1	-0.3	1.4	-0.9	0.1
Essex	0.9	0.4	0.2	1.1	0.7	1.9	0.3	-0.3	-0.6	1.2	-1.1	0.9
Franklin	0.5	0.4	0.2	1.0	0.9	2.0	-0.2	-0.8	-0.3	1.4	-1.2	0.5
Fulton	0.3	0.5	-0.3	0.4	0.1	1.4	0.5	0.9	-0.4	1.0	-1.1	0.8
Genesee	0.6	0.6	0.0	0.7	0.4	-0.2	0.5	0.3	-0.8	1.4	-0.8	0.4
Greene	0.7	0.4	0.0	-0.9	-0.6	0.4	-0.2	2.6	1.0	1.7	-1.0	1.5
Hamilton	0.7	0.5	-0.1	0.7	0.8	1.9	0.2	0.0	-0.9	1.1	-1.1	0.8
Herkimer	0.7	0.7	-0.2	0.4	0.8	1.6	0.3	0.3	-0.8	1.5	-1.2	0.5
Jefferson	0.9	0.3	-0.1	0.5	0.4	1.4	0.3	-0.1	-0.9	1.3	-1.2	0.3
Kings	0.4	0.6	0.2	-1.4	-0.1	0.7	-1.0	1.8	0.3	0.3	-1.2	1.5

New York

Table A-12 (continued). Increase (decrease) in average monthly precipitation (") for New York counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lewis	0.9	0.4	-0.3	0.5	0.7	1.6	-0.3	-0.3	-1.4	1.5	-1.1	0.3
Livingston	0.6	0.6	-0.1	0.3	0.6	0.1	0.8	0.4	-0.5	1.9	-0.7	0.7
Madison	0.8	0.6	0.2	0.7	1.0	0.9	0.7	1.3	-0.4	1.6	-0.6	0.8
Monroe	0.6	0.7	0.0	0.6	0.6	0.1	0.8	0.2	-0.8	1.6	-0.7	0.4
Montgomery	0.4	0.5	-0.1	0.3	0.2	0.9	0.5	1.6	0.1	1.1	-0.9	0.9
Nassau	0.0	0.4	-0.3	-1.5	-1.0	0.0	-1.1	1.6	0.5	0.2	-1.4	1.5
New York City	0.4	0.5	0.1	-1.5	-0.2	0.6	-0.9	1.6	0.2	0.2	-1.2	1.5
Niagara	0.3	0.1	-0.3	0.9	0.5	0.2	0.3	-0.3	-0.3	1.0	-1.3	-0.4
Oneida	0.5	0.4	-0.4	0.6	0.9	1.4	0.5	0.3	-1.0	1.5	-1.0	0.4
Onondaga	0.8	1.0	0.2	0.6	0.8	1.1	0.7	0.7	-0.6	1.7	-0.5	0.9
Ontario	0.5	0.7	0.0	0.2	0.7	0.4	1.1	0.5	-0.6	2.0	-0.6	0.6
Orange	0.7	0.0	-0.1	-1.3	-0.9	0.6	0.3	1.7	0.5	0.7	-1.0	1.2
Orleans	0.4	0.6	-0.3	0.6	0.4	-0.1	0.4	-0.2	-1.0	1.0	-1.2	-0.1
Oswego	0.6	0.8	0.0	0.6	0.4	1.3	0.5	-0.2	-1.0	1.6	-0.8	0.7
Otsego	0.8	0.9	0.2	0.7	0.5	1.1	0.8	1.6	0.4	1.8	-0.6	1.2
Putnam	0.4	0.2	-0.2	-1.3	-0.7	0.1	-0.1	1.4	0.3	0.2	-1.3	1.2
Queens	0.4	0.7	0.1	-1.3	-0.3	0.3	-0.8	1.6	0.3	0.2	-1.2	1.6
Rensselaer	0.7	0.4	-0.5	-0.3	-0.1	0.7	0.1	1.0	1.2	0.9	-1.1	1.1
Richmond	0.5	0.6	0.2	-1.6	0.0	0.8	-0.9	2.0	-0.3	0.4	-1.2	1.4
Rockland	0.4	0.2	-0.1	-1.5	-0.6	0.3	-0.1	1.6	0.0	0.2	-1.3	1.2
St. Lawrence	0.5	0.2	0.1	0.6	0.3	1.7	0.0	-0.6	-0.6	1.2	-1.4	0.3
Saratoga	0.3	0.5	-0.6	0.0	-0.2	1.2	0.4	0.1	0.3	0.8	-1.0	0.9
Schenectady	0.4	0.6	-0.4	-0.1	0.0	0.9	0.5	1.2	0.6	1.1	-1.0	0.9
Schoharie	0.5	0.4	-0.2	-0.1	0.1	0.6	0.1	2.0	0.4	1.4	-0.9	1.1

Table A-12 (continued). Increase (decrease) in average monthly precipitation (") for New York counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Schuyler	0.6	0.5	-0.3	0.2	0.4	-0.2	0.5	0.7	0.7	1.8	-1.0	0.7
Seneca	0.6	0.6	0.0	0.3	0.6	0.2	0.6	0.7	-0.4	1.7	-0.7	0.8
Steuben	0.9	0.4	-0.1	0.4	0.6	-0.4	0.2	0.6	0.8	2.0	-0.7	0.9
Suffolk	0.1	0.2	0.0	-1.3	-0.8	-0.4	-0.9	0.6	0.6	0.6	-1.5	1.6
Sullivan	0.7	0.1	0.0	-0.8	-0.5	0.6	0.8	1.9	0.7	1.4	-0.9	1.3
Tioga	1.0	0.4	0.2	0.1	0.3	0.0	0.2	1.4	1.2	1.5	-0.8	0.7
Tompkins	0.8	0.4	0.0	0.3	0.3	-0.2	0.3	1.0	0.8	1.5	-0.9	0.8
Ulster	0.8	0.1	-0.3	-1.1	-0.9	0.7	0.3	2.2	1.1	1.4	-0.8	1.4
Warren	0.4	0.2	0.0	0.4	0.0	1.2	0.3	0.2	-0.5	0.9	-0.9	1.1
Washington	0.3	0.1	-0.2	0.2	-0.2	1.0	0.2	-0.1	0.1	0.9	-1.1	0.8
Wayne	0.6	0.8	-0.1	0.4	0.6	0.4	0.8	0.6	-0.8	1.5	-0.7	0.7
Westchester	0.2	0.2	-0.3	-1.5	-0.6	0.3	-0.2	1.4	0.7	0.1	-1.4	1.1
Wyoming	0.9	0.8	0.1	0.7	0.5	-0.2	0.7	0.5	-0.6	1.8	-0.5	0.7
Yates	0.4	0.6	-0.2	0.0	0.6	0.0	1.0	0.1	0.0	1.7	-0.8	0.6

Table A-13. Increase (decrease) in average monthly precipitation (") for Rhode Island counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bristol	1.0	0.5	0.3	-0.7	-0.1	0.0	-0.5	-0.1	0.8	1.1	-1.0	1.1
Kent	0.9	0.4	0.2	-0.7	-0.2	0.0	-0.7	0.3	0.9	1.0	-1.4	1.0
Newport	0.6	0.4	0.0	-0.8	-0.1	-0.4	-0.1	-0.4	0.8	1.1	-1.3	1.0
Providence	1.0	0.4	0.1	-0.6	-0.1	0.0	-0.7	0.8	1.0	1.2	-1.6	1.1
Washington	0.7	0.3	0.3	-0.7	-0.1	-0.3	-0.6	-0.1	0.8	1.1	-1.6	1.1

Table A-14. Increase (decrease) in average monthly precipitation (") for Vermont counties between 1980s and 2010s.

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Addison	0.6	0.1	0.2	0.6	0.4	1.3	0.5	-0.5	-0.5	1.0	-1.3	1.0
Bennington	0.7	0.1	-0.6	-0.3	-0.1	1.0	0.0	0.4	0.8	1.3	-1.4	1.2
Caledonia	0.4	0.3	-0.1	0.9	0.5	1.0	1.0	-0.2	0.0	1.0	-1.4	1.0
Chittenden	0.4	0.3	0.2	0.8	0.7	2.1	0.0	-1.0	-0.2	0.9	-1.4	0.9
Essex	0.6	0.4	-0.2	0.7	0.7	1.2	0.2	-0.1	0.2	1.1	-1.4	1.1
Franklin	0.3	0.3	0.3	0.9	0.2	1.4	0.1	-0.7	0.5	0.7	-1.7	0.9
Grand Isle	0.5	0.5	0.5	0.9	0.5	1.6	-0.2	-0.5	0.2	1.1	-1.1	0.7
Lamoille	0.3	0.3	0.1	1.0	0.1	1.9	-0.1	-0.6	-0.3	0.8	-1.5	1.1
Orange	0.4	0.0	0.0	0.4	0.0	1.5	0.9	0.2	-0.4	1.2	-1.5	1.1
Orleans	0.4	0.3	0.0	1.3	0.5	1.6	0.4	0.1	0.5	1.0	-1.3	1.0
Rutland	0.6	0.1	0.1	0.4	0.1	1.2	0.3	0.0	-0.6	1.3	-1.5	1.1
Washington	0.1	0.3	0.2	0.7	0.4	1.8	0.8	-0.7	-0.3	1.0	-1.4	1.0
Winham	0.7	0.0	-0.7	-0.6	-0.3	1.0	-0.1	1.3	0.7	1.6	-1.4	1.5
Windsor	0.4	0.0	-0.3	0.2	-0.2	1.3	0.6	0.3	-0.3	1.3	-1.5	1.2