Climate Change Effects on New England’s Forests

Dr. Pamela Templer
Boston University
ptempler@bu.edu
Climate Change

- Air Pollution
- Introduced Pests
- Land-Use Change
- Urbanization
Atmospheric CO$_2$ at Mauna Loa Observatory, Hawaii

Scripps Institution of Oceanography
Global Temperatures Rising

The graph illustrates the increase in global temperatures and CO₂ concentration over the years from 1880 to 2000. The blue bars represent the global temperature in °F, while the red line indicates the CO₂ concentration in ppm.
2 °C increase

Winter Air Temperatures Rising and Snowpack Shrinking
Winter Air Temperatures Rising and Snowpack Shrinking

Hubbard Brook

Winter Air Temperature (°C)

Maximum Snow Depth (cm)

2 °C increase

26 cm depth
20 day decrease

Hubbard Brook
Help, the mountains are melting!
The case of the disappearing ski slopes
By NOAH SCHAUER | November 7, 2012

CHRONICLE

In 100 years, maple sap will flow a month earlier
By Krishna Ramanujan

Nov. 10, 2010

As the climate warms this century, maple syrup production in the Northeast is expected to slightly decline by 2100, and the window for tapping trees will move earlier by about a month, reports a Cornell study.

Currently, the best times to tap maple trees are within an eight-week window from late winter to early spring when temperatures cause freezing at night and thawing by day.

"By 2100, we can expect to begin tapping maples closer to Christmas in the Northeast," said Brian Chabot, professor of ecology and evolutionary biology and a co-author of a paper on climate changes and maple sugar production that appeared earlier this year in the journal Climate Change.

Sap flow is related to pressure changes in the trees' xylem, which are tubes beneath the bark that carry sap from the maple's roots up to the leaves. As maple trees freeze in winter, gases are pushed out of the xylem into surrounding tissues, and negative pressure is created within the xylem compared with atmospheric pressure. When the trees thaw, the gases expand and dissolve back into the sap.

Brian Chabot
Mike Farrell, director of the Uihlein Sugar Maple Research and Extension Field Station in Lake Placid, N.Y., taps a maple tree.
Increased Winter Temperatures and Reduced Snowpack Extent Over Next 100 Years in Northeastern United States
Reduced Snowpack Leads to Soil Freezing
Reduced Snowpack Leads to Soil Freezing
Why Focus on Soil Freezing?

Could damage biota in forests:
- Plant Roots
- Microbes
- Arthropods

↓

Water & Air Quality
Why Focus on Soil Freezing?

Could damage biota in forests:
- Plant Roots
- Microbes
- Arthropods

↓

Water & Air Quality
Carbon Storage in Forests
Why Focus on Soil Freezing?

Could damage biota in forests:
- Plant Roots
- Microbes
- Arthropods

Water & Air Quality
Carbon Storage in Forests

Why does this matter?
Why Focus on Soil Freezing?

Could damage biota in forests:
- Plant Roots
- Microbes
- Arthropods

Water & Air Quality
Carbon Storage in Forests

Why does this matter?
Carbon uptake by ecosystems offsets fossil fuel emissions of CO₂ by ~30%
Carbon Uptake by Forests Offsets 30% of \( \text{CO}_2 \)
Emissions from Fossil Fuel Combustion
Do reduced snowpack and increased soil frost decrease nutrient uptake by trees and ecosystem carbon storage in forests?
Snow-Removal Experiments at Hubbard Brook and Harvard Forest

Hubbard Brook

Harvard Forest

Sugar maple - American beech

Red maple - Red oak
Snow-Removal Experiments
at Hubbard Brook and Harvard Forest

\[ n = 4 \text{ reference and 4 treatment plots at Hubbard Brook} \]
\[ n = 3 \text{ reference and 3 treatment plots at Harvard Forest} \]
Snow and Soil Frost Depth Measurements

Snow Depth

Frost tubes with methylene blue dye
Snow and Soil Frost Depth Measurements

Snow Depth

Frost tubes with methylene blue dye

clear = frozen
blue = unfrozen
Smaller Snowpack Increases Soil Frost Depth

Sorensen et al. (2016) *Biogeochemistry*
Soil Frost Induces Root Injury of Sugar Maple Trees

Commerford et al. (2013) Oecologia
Soil Frost Induces Root Injury of Sugar Maple Trees

Commerford et al. (2013) *Oecologia*

![Graph showing relative electrolyte leakage (%)]

- **Root Damage**
  - Reference
  - Snow Removal

Commerford et al. (2013) *Oecologia*
Soil Frost Induces Root Injury of Sugar Maple Trees

Commerford et al. (2013) Oecologia
Soil Frost Reduces Nitrogen Uptake by Sugar Maple Trees

Socci and Templer (2011); Campbell et al. (2014)
Soil Frost Reduces Nitrogen Uptake by Sugar Maple Trees

Net Uptake ($\mu$mol N g root$^{-1}$ hr$^{-1}$)

- Reference
- Snow removal

$P < 0.05$

36%

April 22 April 30 May 6 May 13 May 21 May 27

Socci and Templer (2011); Campbell et al. (2014)
Soil Frost Induces Elevated $\text{NO}_3^-$ in Leachate

- Reference
- Snow removal

Campbell et al. (2014) *Global Change Biology*
Why Care about Nitrogen Leaching?

- Release of N$_2$O
- Reduced forest productivity
- Acidification of stream water
- Eutrophication (algal blooms)
- Human health effects
Reduced Snowpack and Increased Soil Freezing

• damage roots and reduce nitrogen uptake by maple trees

(Comerford et al. 2013, Campbell et al. 2014)
Reduced Snowpack and Increased Soil Freezing

- damage roots and reduce nitrogen uptake by maple trees
  (Comerford et al. 2013, Campbell et al. 2014)
- increase nitrogen leaching
  (Campbell et al. 2014)
Do reduced snowpack and increased soil frost decrease ecosystem carbon storage in forests?
Snowpack Declines Decrease C Storage in Forests

Cumulative Carbon in Trees (Mg C ha⁻¹)

- Reference
- Snow Removal

Snow Removal Period

2008 2009 2010 2011 2012 2013 2014

---

* Significant difference
** Highly significant difference
Snowpack Declines Decrease C Storage in Forests

Cumulative Carbon in Trees (Mg C ha\(^{-1}\))

![Graph showing cumulative carbon in trees over time with reference and snow removal lines, with significant differences indicated by asterisks.](image)

- **Photosynthesis (CO\(_2\) Uptake)**
- **Tree Growth (CO\(_2\) Uptake)**
Cumulative Carbon in Trees (Mg C ha\(^{-1}\))

Climate change in winter: 40% decrease carbon storage
Snowpack Declines Decrease C Storage in Forests

Cumulative Carbon in Trees (Mg C ha⁻¹)

Photosynthesis (CO₂ Uptake)

Tree Growth (CO₂ Uptake)

Soil Respiration (CO₂ Losses)

Stem Respiration (CO₂ Losses)
Do reduced snowpack and increased soil frost decrease ecosystem carbon storage in forests?

Large Snowpack
Little soil frost
Do reduced snowpack and increased soil frost decrease ecosystem carbon storage in forests?

Large Snowpack
Little soil frost

Small Snowpack
Deep soil frost
Do reduced snowpack and increased soil frost decrease ecosystem carbon storage in forests?

Large Snowpack
Little soil frost

Small Snowpack
Deep soil frost
Do reduced snowpack and increased soil frost decrease ecosystem carbon storage in forests?

Large Snowpack
Little soil frost

Small Snowpack
Deep soil frost

15% reduction C storage across northern forest

* Hubbard Brook
What are combined effects of colder soils in winter + warmer soils in the growing season?
Climate Change Across Season Effects Experiment
Climate Change Across Season Effects
CCASE
Climate Change Across Season Effects (CCASE)

Determine how warmer temperatures in the growing season and smaller snowpack affect carbon sequestration in northern forests.
Climate Change Across Season Effects (CCASE)

Determine how warmer temperatures in the growing season and smaller snowpack affect carbon sequestration in northern forests.

14 X 11m² plots in hardwood forest
• 2 plots: reference
• 2 plots: soils warmed 5°C in growing season
• 2 plots: soils warmed 5°C in growing season and less snow in winter
Soil Temperature at CCASE

- reference
- warmed in growing season
- warmed in growing season & snow removal in winter
Winter:
Soil Freeze/Thaw Cycles

Soil Temperature (°C)

Soil Temperature at CCASE
reference
warmed in growing season
warmed in growing season & snow removal in winter

Templer et al. (2017) PLOS One
Growing Season:

- Soils Warmed 5°C

Soil Temperature (°C)

Winter:

- Soil Freeze/Thaw Cycles

#1 #2 #3 #4

Templer et al. (2017) PLOS One
Soil Frost Damages Roots and Reduces N Uptake

Rebecca Sanders-Demott (PhD)
Soil Frost Damages Roots and Reduces N Uptake

Rebecca Sanders-Demott (PhD)

Root Damage

$P < 0.05$

$R^2 = 0.75$
Soil Frost Damages Roots and Reduces N Uptake

Rebecca Sanders-Demott (PhD)

Root Damage

$P < 0.05$

$R^2 = 0.75$
Soil Frost Damages Roots and Reduces N Uptake

Rebecca Sanders-Demott (PhD)
Soil Frost Induces Nitrogen Losses

$P = 0.055$

Reference

Warmed In Growing Season

Warmed + Freeze/Thaw in Winter

Rebecca Sanders-Demott (PhD)
Soil Frost Induces Nitrogen Losses

$P = 0.055$

Reference: $\mu g \text{NH}_4$-N g resin$^{-1}$ day$^{-1}$

Warmed In Growing Season: $\mu g \text{NH}_4$-N g resin$^{-1}$ day$^{-1}$

Warmed + Freeze/Thaw in Winter: $\mu g \text{NH}_4$-N g resin$^{-1}$ day$^{-1}$
Aboveground Productivity & Carbon Uptake by Trees

• Litterfall baskets: 4 per plot
• Dendrometer bands on all trees \( \geq 10 \) cm diameter
• 21-24 trees per plot: mixed hardwood stand
Cumulative Aboveground Carbon Since 2014

- Reference
-△ Warmed in Growing Season
-● Warmed in Growing Season + Freeze/Thaw Cycles in Winter
Cumulative Aboveground Carbon Since 2014

Warmed soils increase aboveground tree growth by 50%
Cumulative Aboveground Carbon Since 2014

Cumulative Carbon (Mg C ha\(^{-1}\))

- Reference
- Warmed in Growing Season
- Warmed in Growing Season + Freeze/Thaw Cycles in Winter

Warmed soils increase aboveground tree growth by 50%

\(\frac{2}{3}\) Offset by soil freeze/thaw cycles in winter
• Winter freeze-thaw cycles injure roots and reduce nitrogen uptake by trees, not offset by growing season warming.
Conclusions

• Winter freeze-thaw cycles injure roots and reduce nitrogen uptake by trees, not offset by growing season warming
• Growing season warming leads to greater tree growth and carbon uptake, but offset by soil freeze-thaw cycles in winter
Acknowledgements

Amey Bailey, Scott Bailey, Frank Bowles, Laura Clerx, Steve Decina, Ian Halm, Jamie Harrison, Stephanie Juice, Brendan Leonardi, Mary Martin, Risa McNellis, Rebecca Sanders-DeMott, Patrick Sorensen, Amy Werner, Geoff Wilson, Jackie Wilson, Gabe Winant, Tammy Wooster
Climate Change Effects on New England’s Forests

Dr. Pamela Templer
Boston University
ptempler@bu.edu