Climate Impacts on Hemlocks & Hemlock Woolly Adelgid in the Northeast

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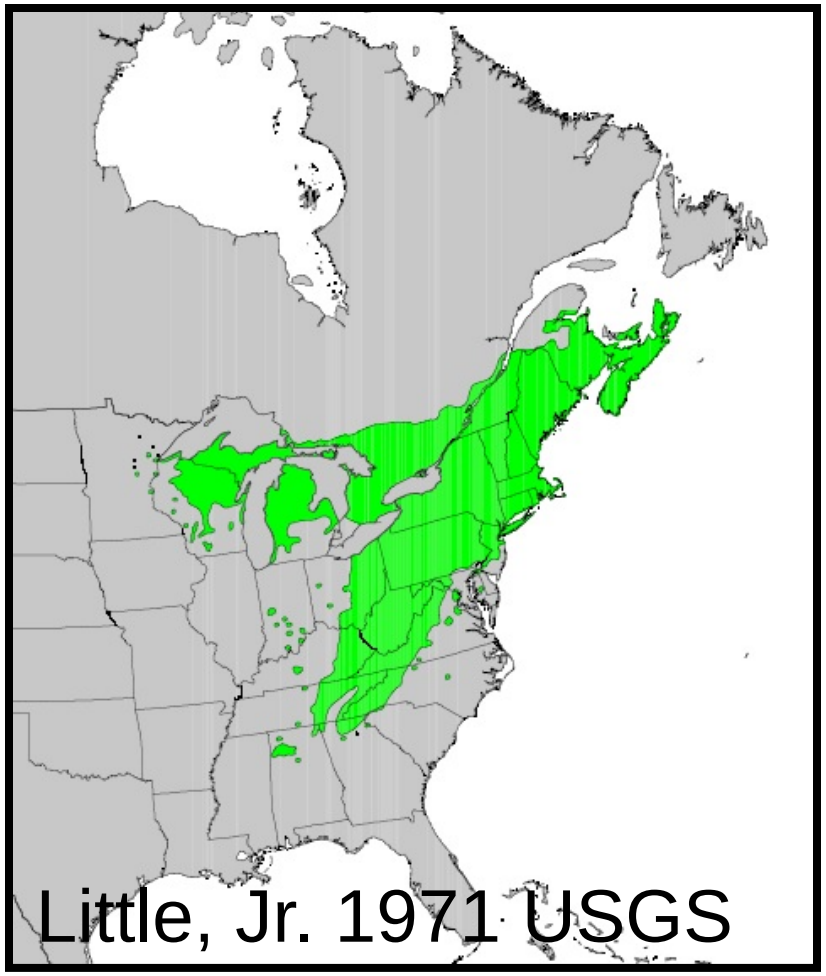
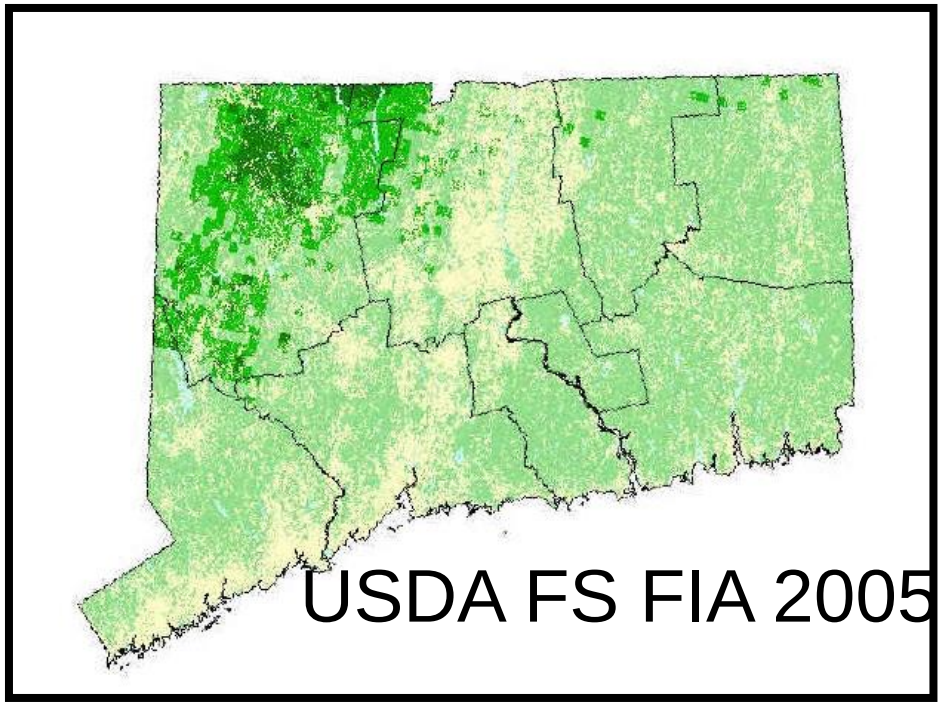
Range of Eastern Hemlock, *Tsuga canadensis*



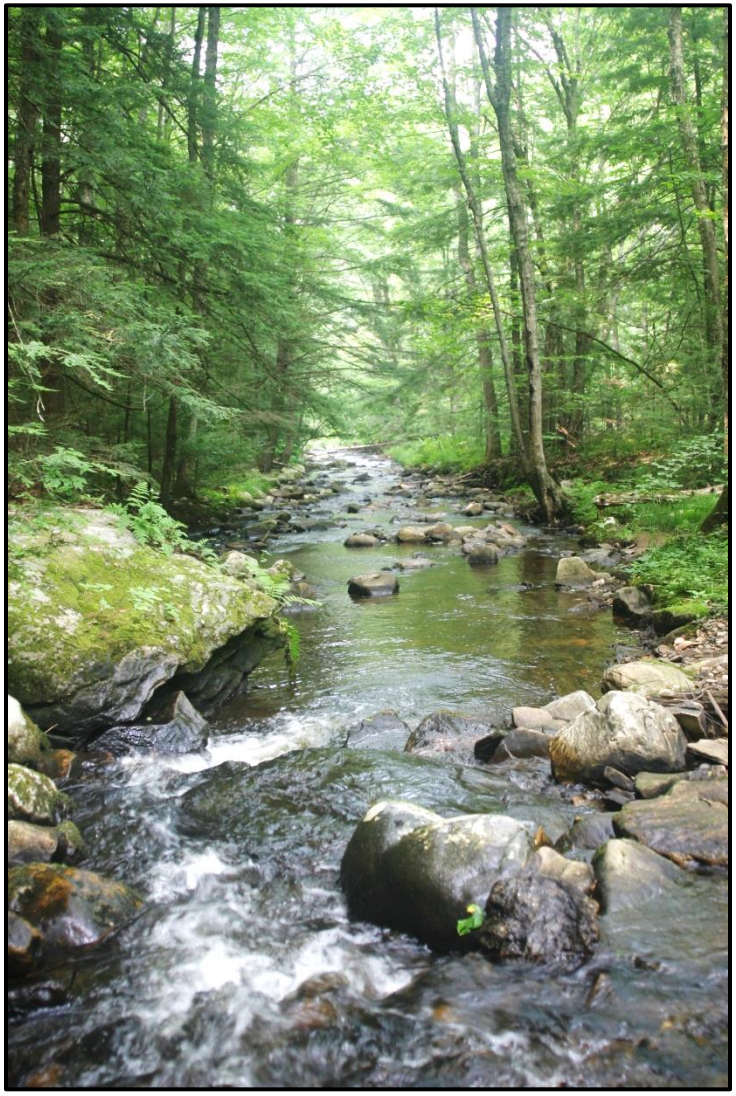
%basal area/acre



Nonforest
<5%
5-20%
20-50%
>50%

Importance of Eastern Hemlock

Crucial habitat for wildlife, birds, fish and rare amphibians

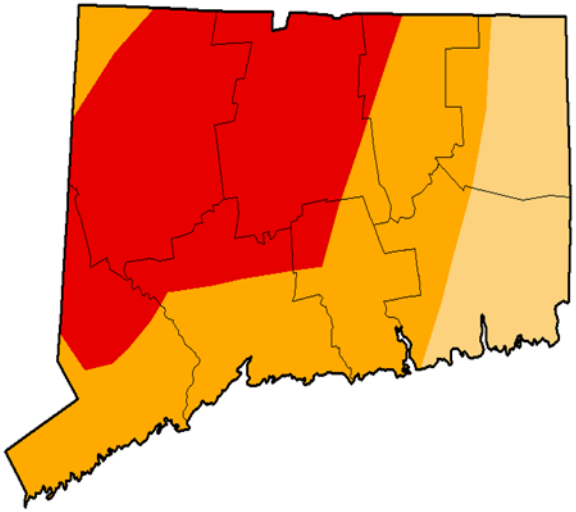


Optimal Hemlock Growing Conditions

- Cool humid climates
- 29- >50 inches annual precipitation
- Adapts to a variety of soils: mostly moist with good drainage
- Occurs at sea level – 2,400 ft in the northern range; 2,000-5,000 ft in southern mountains
- In pure to mixed forest stands
- Very shade tolerant & long lived species

Hemlock's Critical Primary Stressor: Drought

CT's Severe or Extreme Drought
2015-2017, lasted 11-22 mo



D0 Abnormally Dry

D1 Moderate Drought

D2 Severe Drought

D3 Extreme Drought

D4 Exceptional Drought

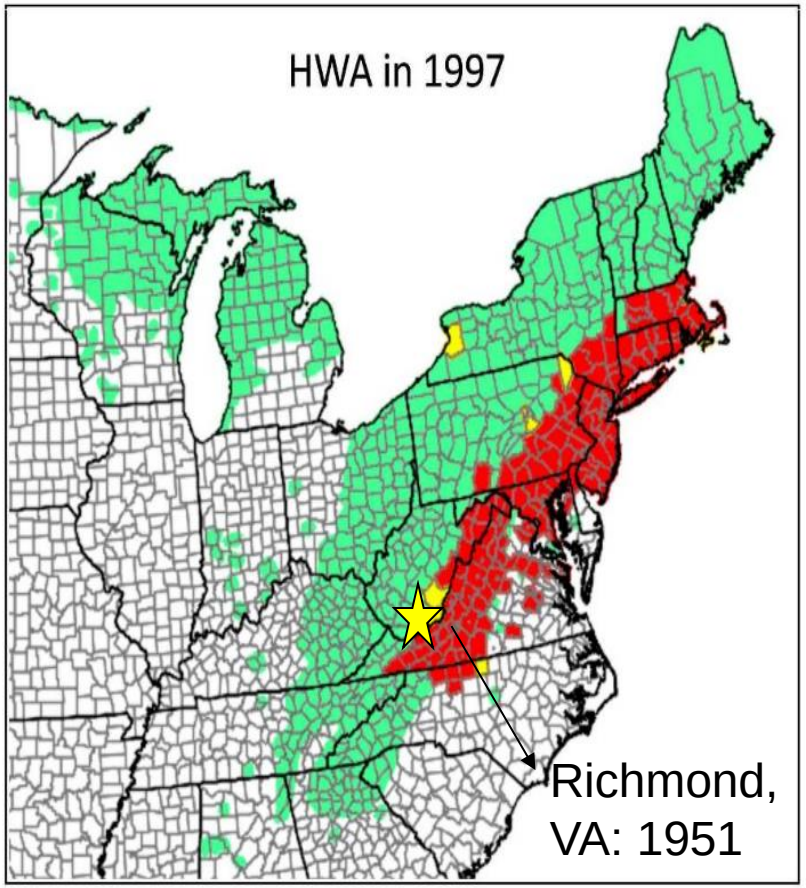
Impacts of Extreme Drought

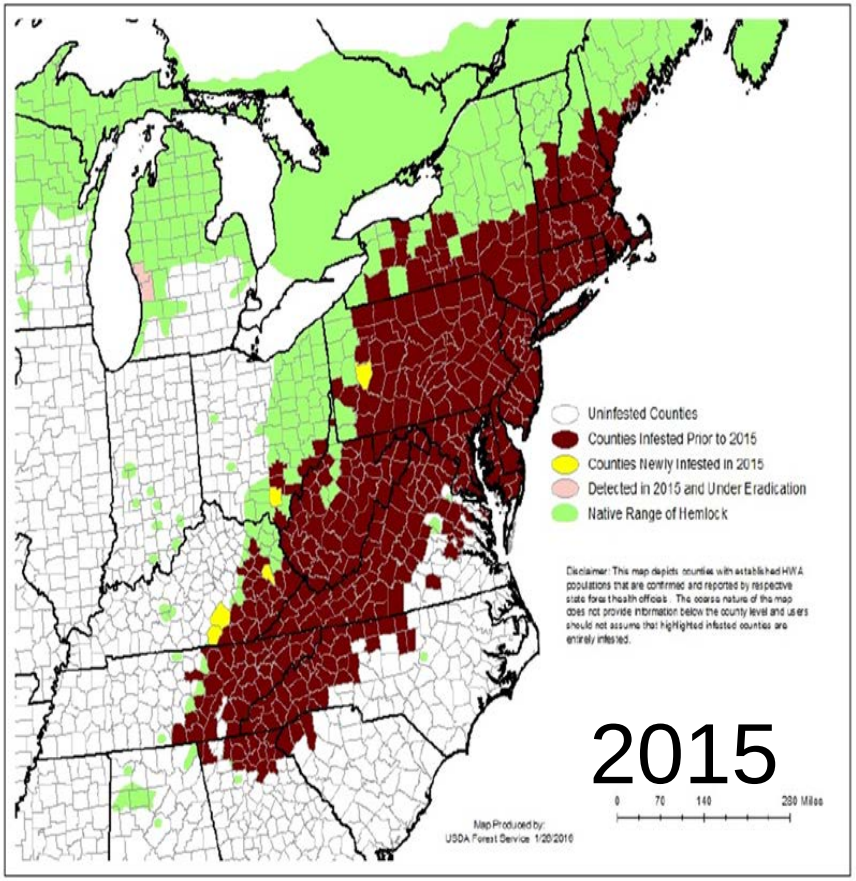
- Shallow-rooted, moisture-loving hemlocks were severely impacted by prolonged drought 2015-2017
- Compounded by **extreme winter desiccation by wind chills -20 to -30°F** in winter of 2018

Hemlock Woolly Adelgid, HWA, *Adelges tsugae*, in Eastern US

Origin: Southern Japan

HWA: Then and Now





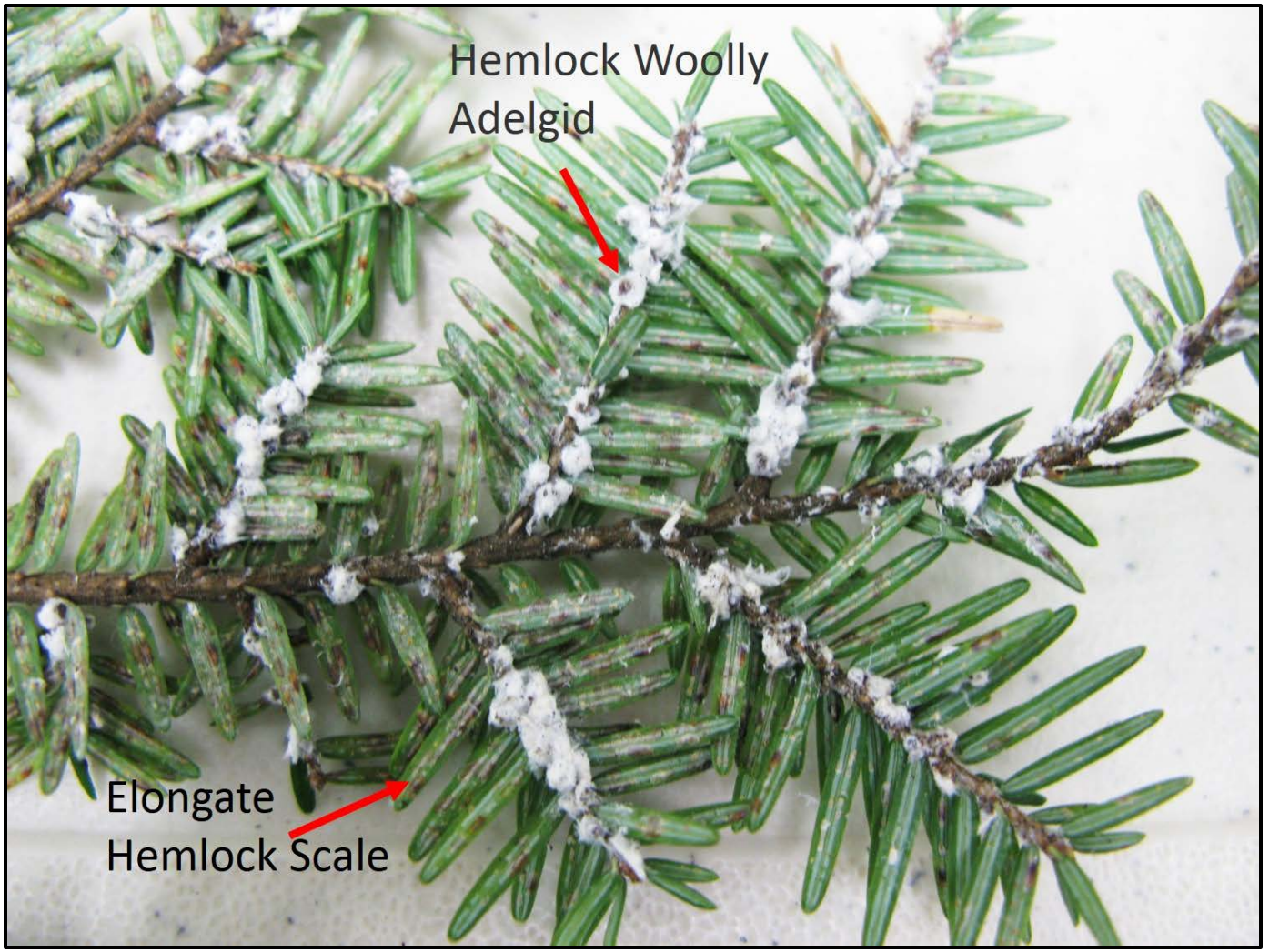
Adapted from USDA Forest Service HWA maps

Also in Canada: Ontario (Fidgen 2014);
Nova Scotia 2017

Damage to Hemlocks

- HWA feeds on xylem storage cells, which reduces new shoot production
- Needle drop leads to thin crowns & twig dieback
- Heavy infestations, in conjunction with other stressors, can lead to tree death in 4-6 years in marginal growing sites
- Other serious pests: Elongate hemlock scale, EHS (exotic) and hemlock borer (native)

DOUBLE TROUBLE: HWA + EHS

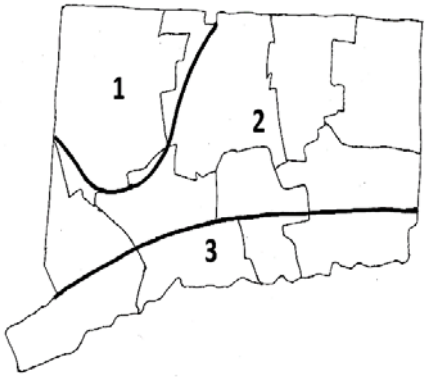


Consequences of Hemlock Decline and Mortality

- Significant ecosystem impacts, changes in diversity and community structure
- Potential loss of wildlife habitat & winter cover in northern forests
- Habitat loss for dependent birds
- Warmer stream temperatures affecting native brook trout survival
- Increased nutrient losses to soil water
- Increased rainwater runoff

A Changing Climate of Extremes in the Northeast…

- Warmer winters vs. Extreme cold outbreaks
- Extreme droughts vs. Increased precipitation and flooding
- Hotter earlier springs vs. Extended cool springs
- Hotter summers, extended fall seasons
- Affects the timing of biological processes



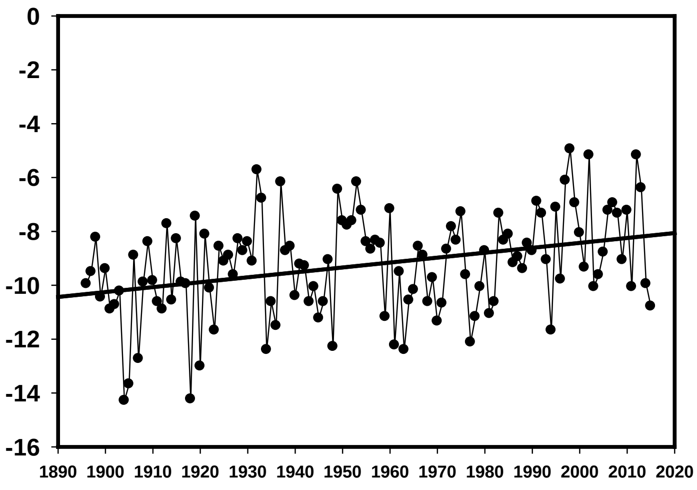
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

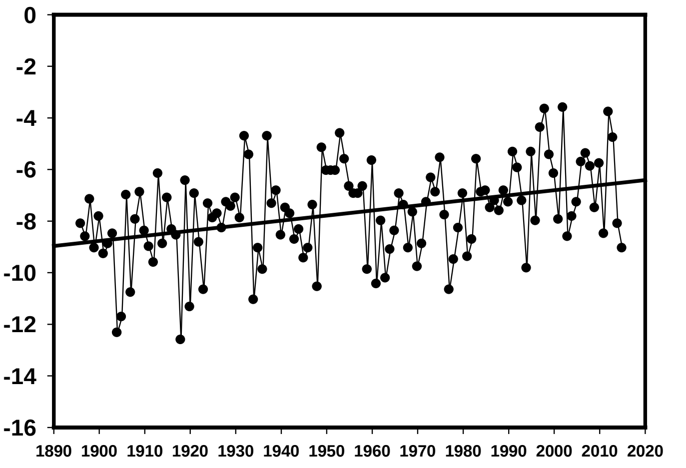
Climatic Divisions of CT

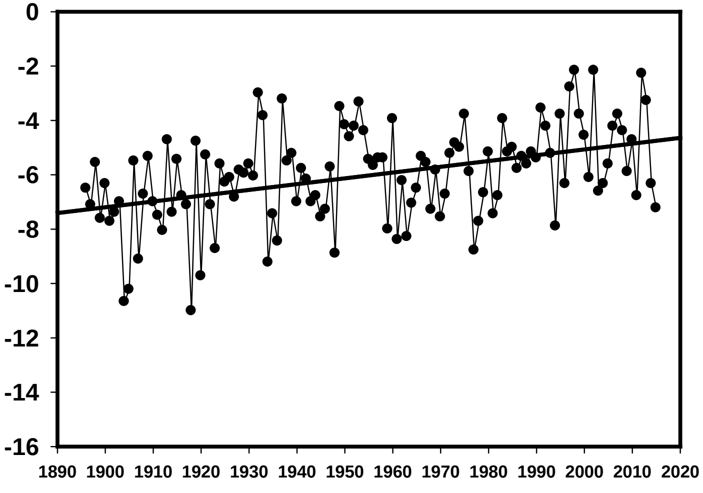
1 = Northwest
2 = Central
3 = Coastal

The significant rise in minimum winter temperatures in CT climate divisions

Minimum Winter Temp. °C



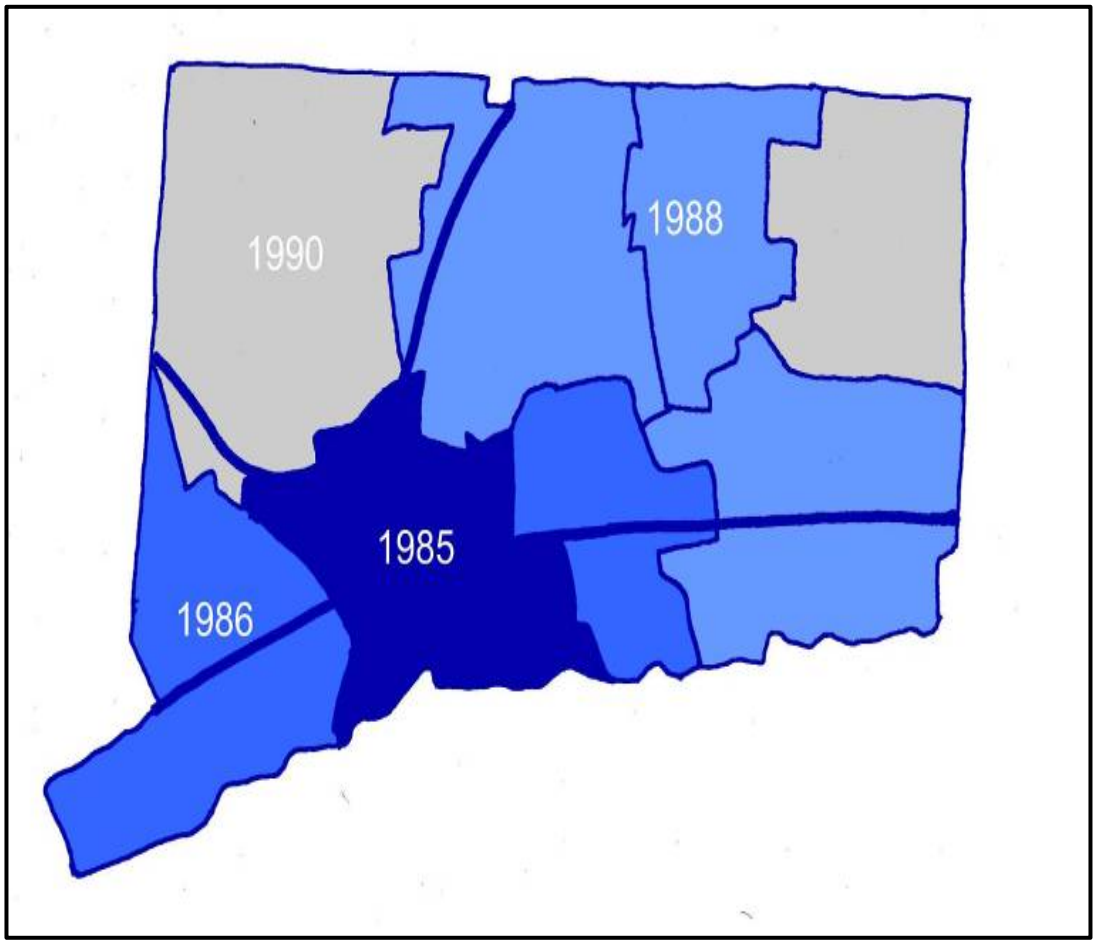




1895-2015

Data from NOAA

Progression of HWA in CT



By 1997, 97% of CT towns had reported HWA infestations

33 years of HWA

Winter Effects on HWA Survival

Life Cycle of HWA

Adults → + Eggs

Developing Nymphs

WINTER

Hatch

FALL

SPRING

SISTENS

PROGREDIENS

Summer N1 dormancy

SUMMER

Winged sexuparae

Adults + Eggs

Hatch

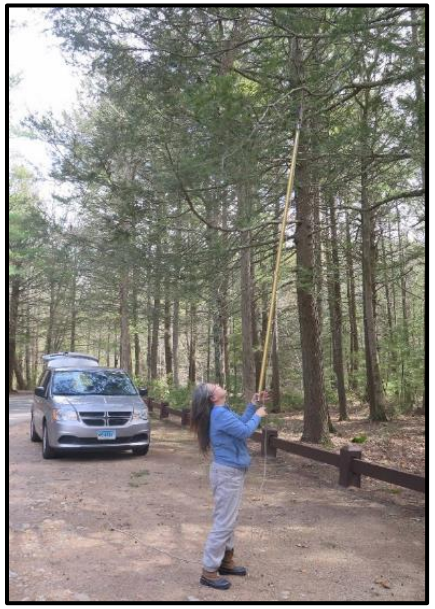
Hatching crawlers dispersed by wind, birds, wildlife and humans

Developing nymphs

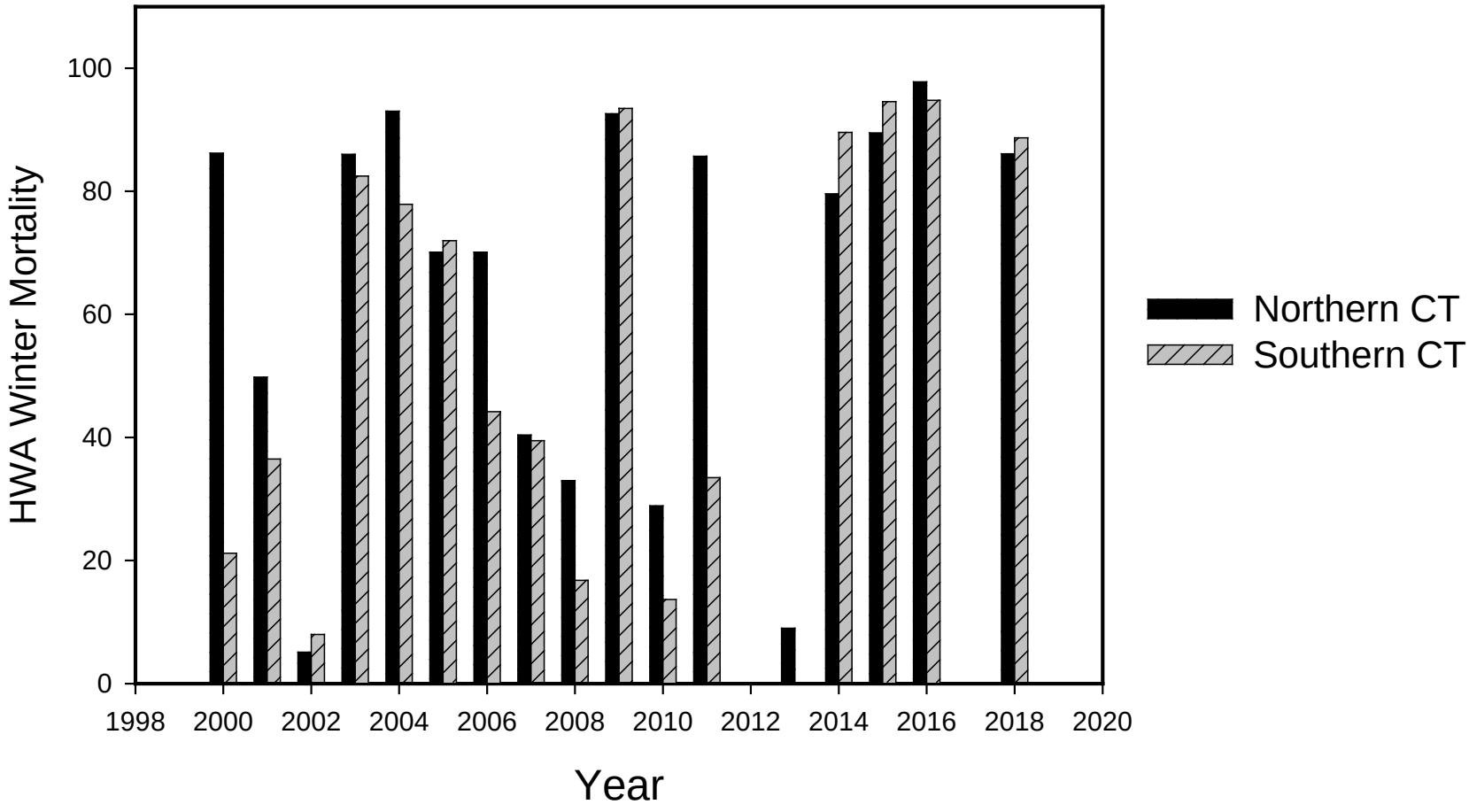
15 Years of HWA Winter Mortality Assessments in CT

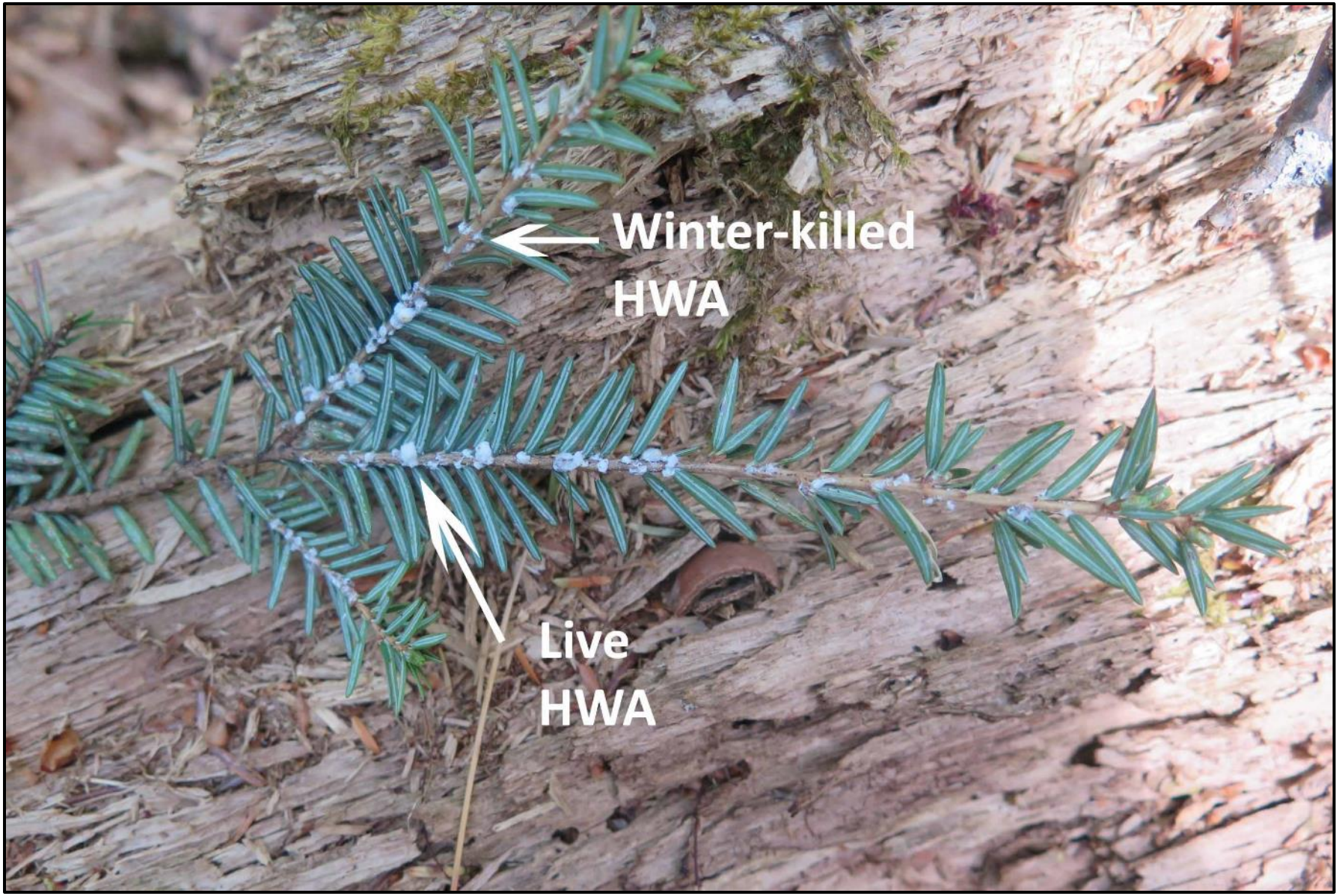
•10 trees/forest site, infested HWA tips sampled late winter-early spring above 4 ft snow line

- 1,000 HWA counted per site under microscope
- >245,000 total from 208 sites from 2000-2015
- Weather data from nearest official station



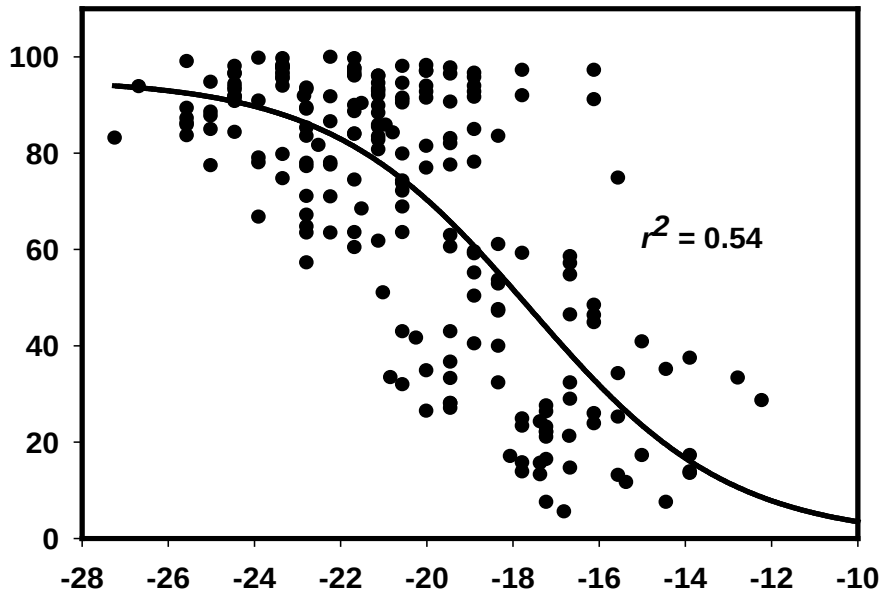
Winter Mortality of HWA in CT 2000-2018




Winter-killed
HWA
Live
HWA

Important Determinants of HWA Winter Mortality in CT

Mean %HWA Mortality per site



Minimum winter daily temperature °C

Absolute minimum daily winter temperature (Dec.- Feb.) is the best predictor

Other Important Factors

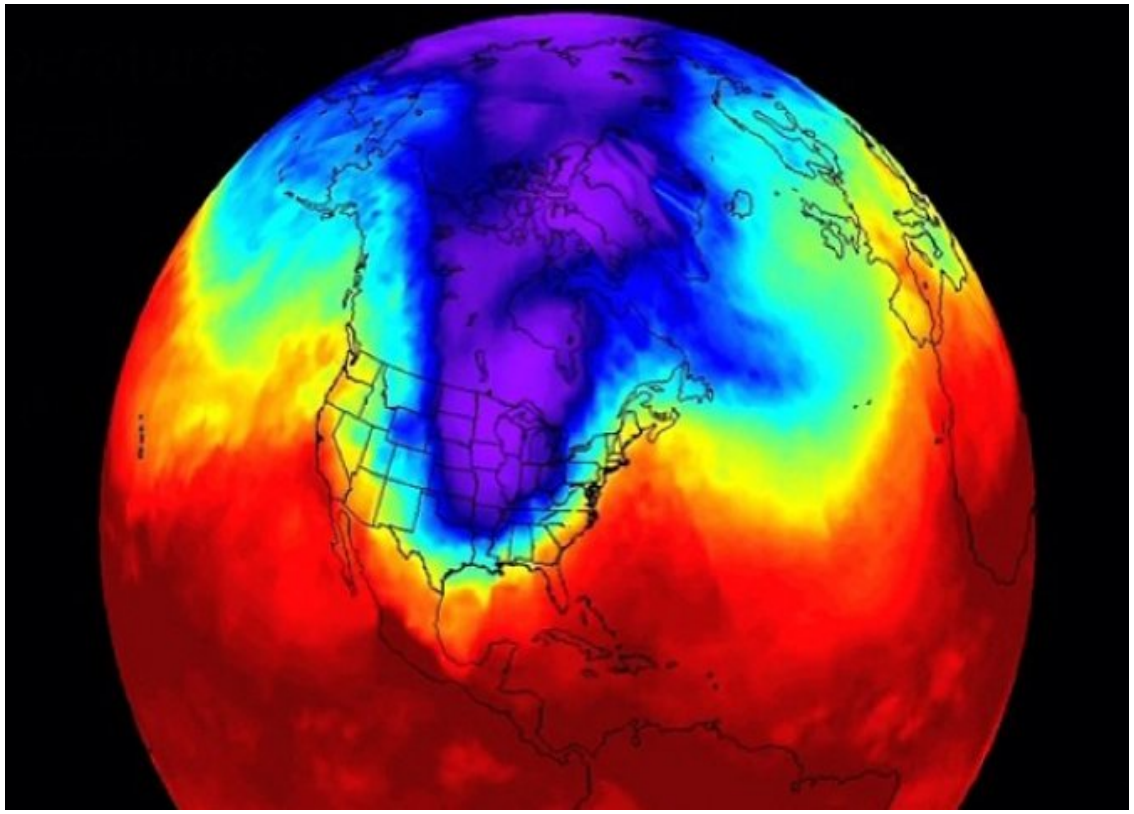
- Number of subzero days (Base is 0°F or -17.8°C)
- Duration and intensity of subzero cold, expressed as Negative Degree Days or NDD
- HWA can be killed by prolonged severe winters or abrupt and extreme cold snaps
- Snow cover protects HWA

(Cheah 2017)

Predictors of CT HWA Winter Mortality

Climate Division	90% HWA Mortality			99% HWA Mortality
1	-11°F	5.5d	-130 NDD	-17.7°F
2	-8.3°F	6d	-100 NDD	-13.7°F
3	-6.2°F	2.6d	- 45 NDD	-13°F

Polar vortex: a cause of extreme winters

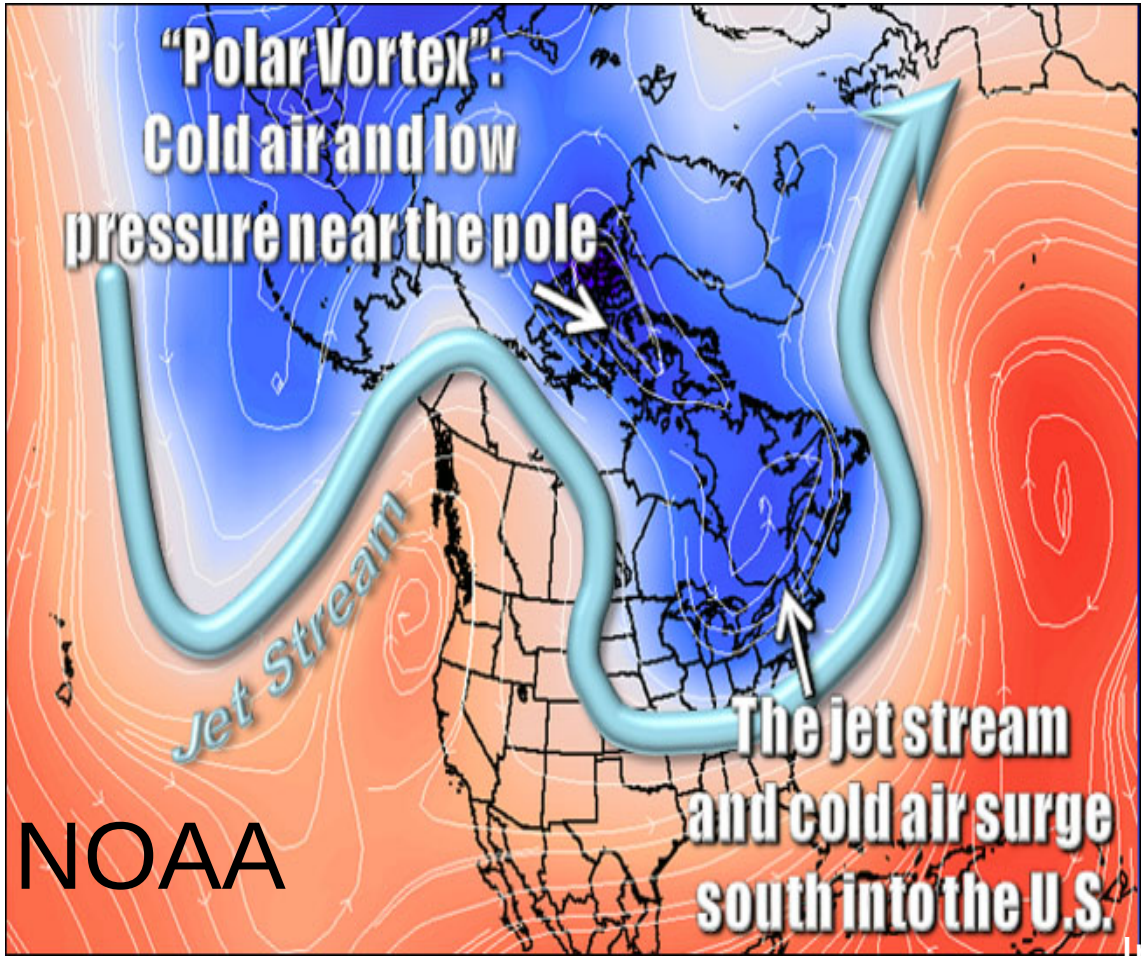


NASA

Major Polar Vortex Events over North America:

1985, 1994, 1996, **2014, 2015; 2016, 2018**

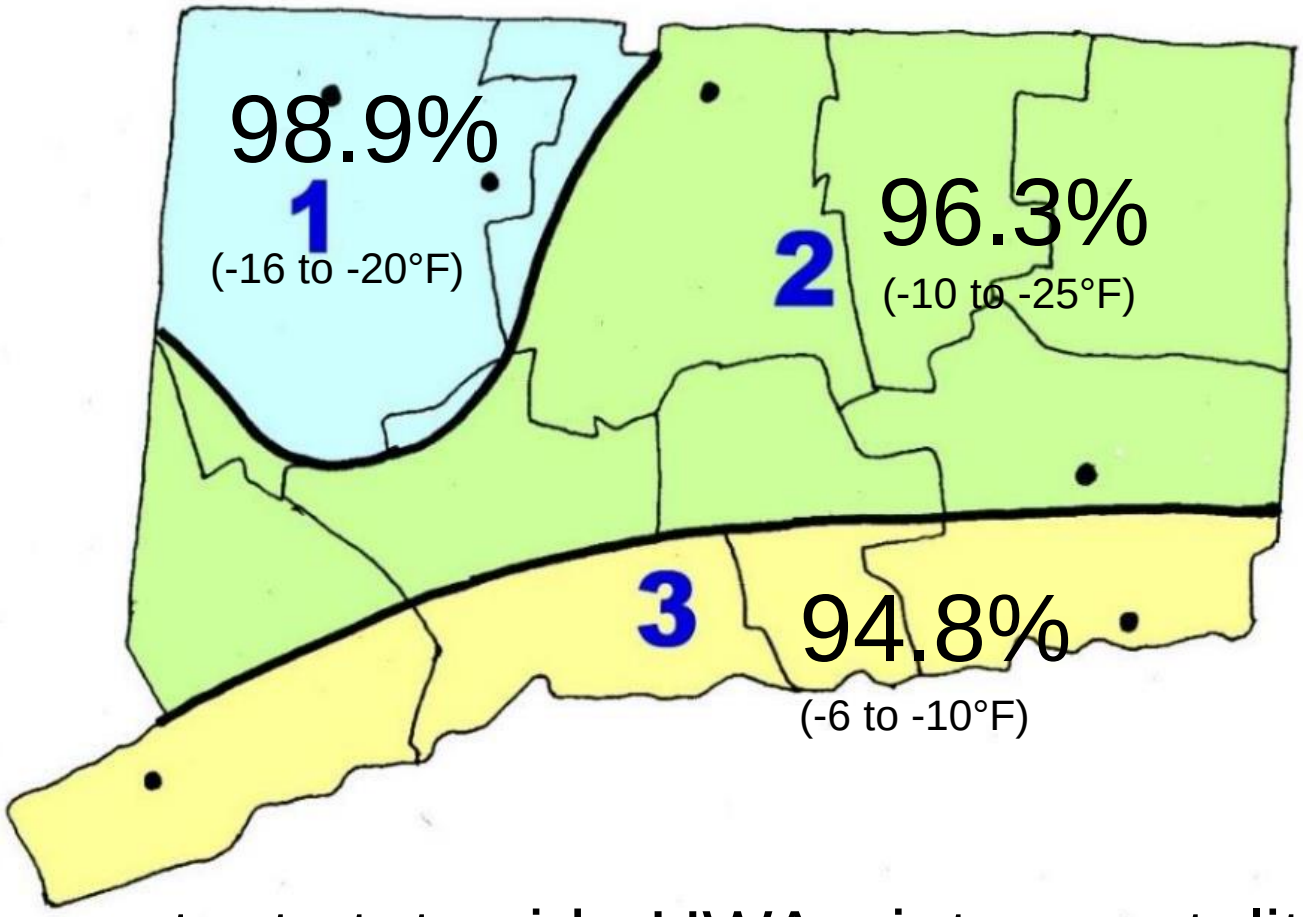
More recent & frequent polar vortex events: HWA reduced to lowest levels



NOAA

Dead HWA

2016 Winter Mortality of HWA



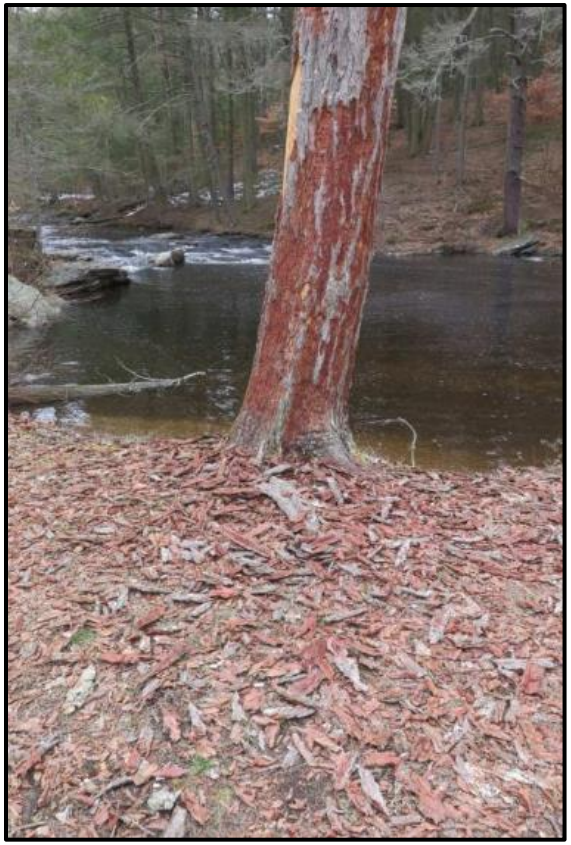
The greatest statewide HWA winter mortality in CT (mean 97%) during the warmest winter on record

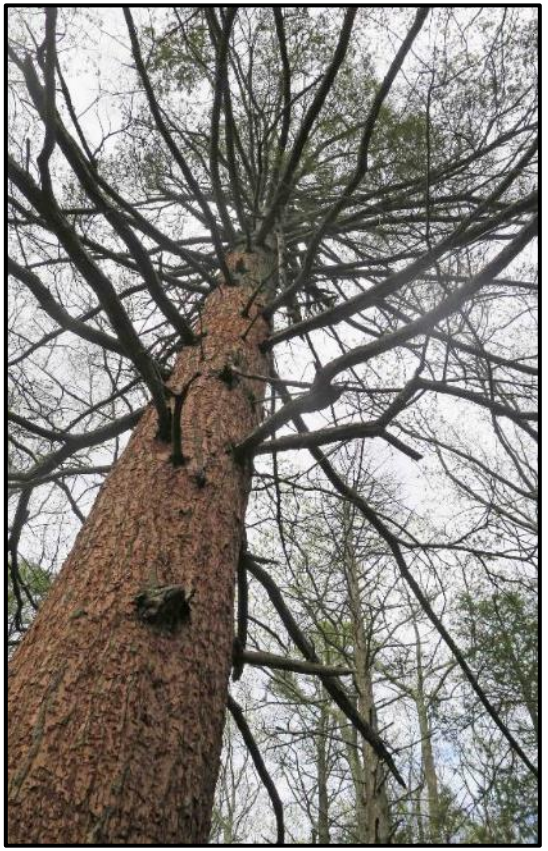
Changing Climate & Pest Emphasis

HWA contraction but rise and spread of Elongate Hemlock Scale, EHS

Accelerated Decline of Hemlocks Due to Elongate Hemlock Scale

Extreme Drought Precipitated Native Hemlock Borer Outbreaks in 2016-2017





Hemlock Resilience & Recovery

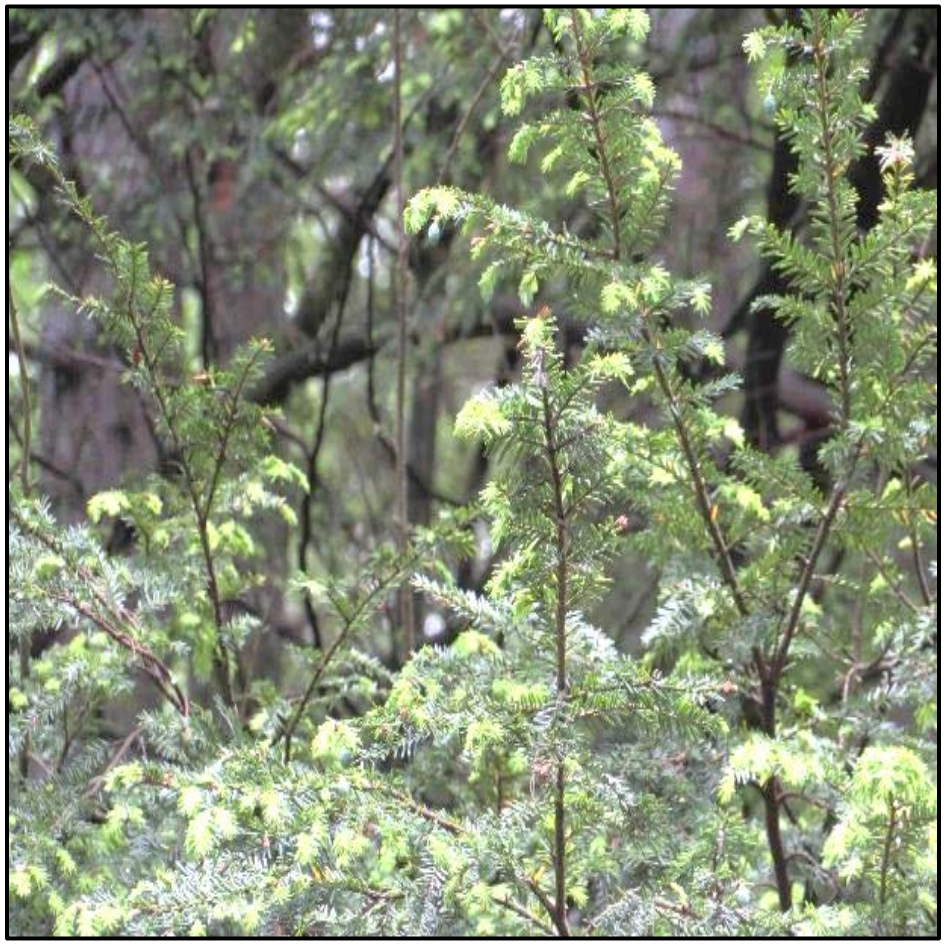
2015

2018

Hemlock Refoliation

after an above normal wet 2017 spring

People’s State Forest, Barkhamsted, August 2017



September 2015

Opportunity to target HWA survivors before resurgence

Sasajiscymnus (=Pseudoscymnus) tsugae

1st US HWA biological control agent released by CAES

Available commercially (www.tree-savers.com)

Attributes for Biological Control

- Strongly prefers to feed on HWA
- 2 generations, highly synchronized life cycle
- All stages actively feed and develop on all stages of HWA from spring to fall
- Long-lived adults overwinter
- High lifetime fecundity (250-500 eggs/female)
- Adults do not enter diapause in the summer or under laboratory rearing conditions
- Amenable to mass rearing

Can *Sasajiscymnus tsugae* survive Northeast winters?

- Shown to overwinter and establish in CT between 1996-2005
- Survived -7°F in field experiments in ME + CT
- *S. tsugae* has been consistently recovered, overwintering successfully from Kittery to Wiscassett in coastal Maine (Colleen Teerling, Maine Forest Service, pers. comm.)
- Also survived heatwaves and drought

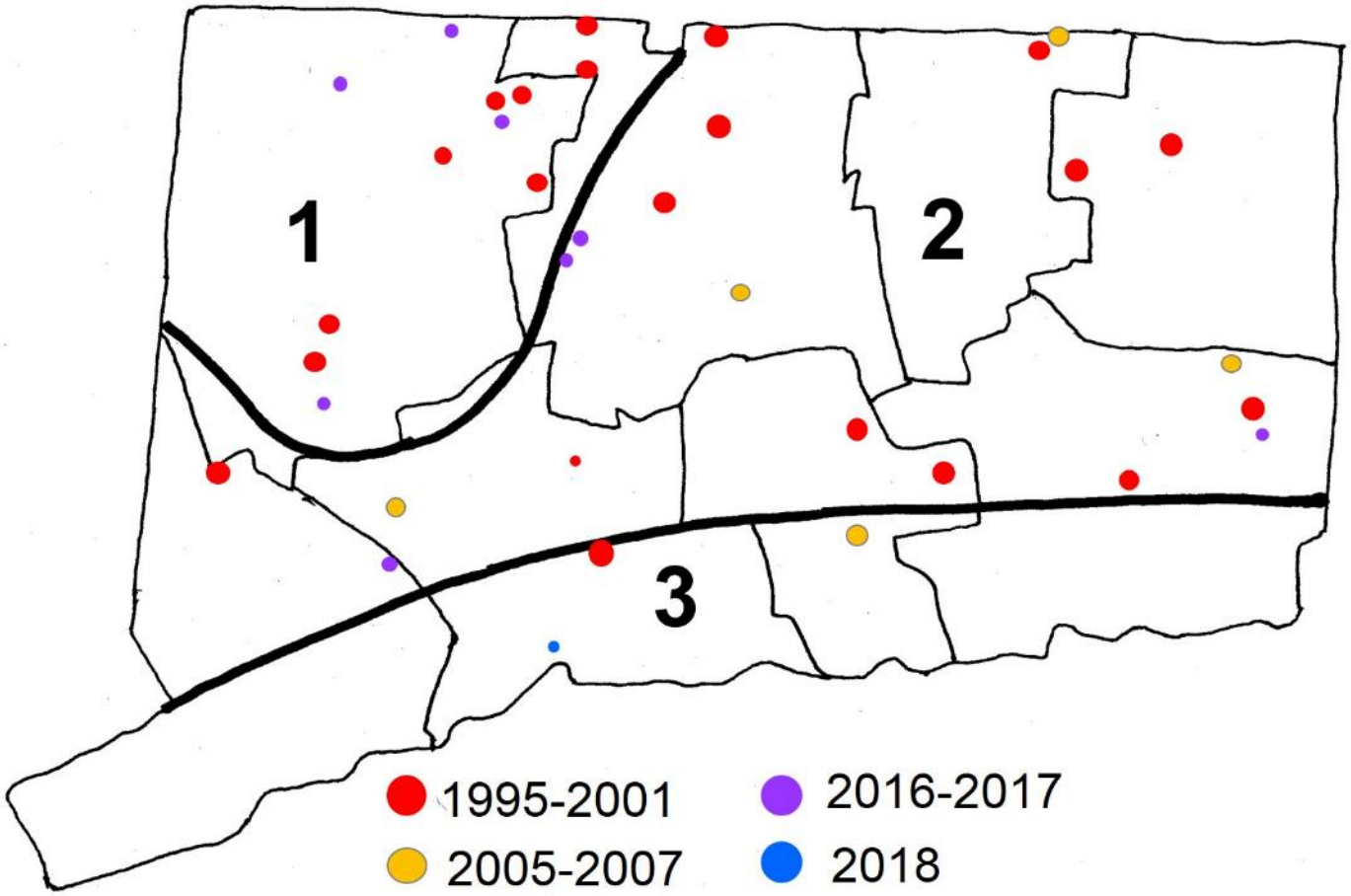
Unique Predation Plasticity

Field Predation of HWA During Hot Spring and Summer

….voraciously fed on 2nd progrediens generation and dormant HWA sistens during the extreme heat of 2016 and in 2017

S. tsugae uniquely feeds on dormant sistens N1 all through the hot humid summer into fall: no other HWA predator does this

S. tsugae release sites 1995-2018



…>178,000 released in CT from 1995-2018

Plant Science Day PLOT 50

Acknowlegments

- *X. Asbridge, B. Beebe, J. Fengler, M. K. Frost, R. Hiskes, J. Preste, P. Trenchard, S. Sandrey, and J. Winiarski of the CT Agricultural Experiment Station for valuable technical assistance*
- *J. Bronson, R. Russ, from Great Mountain Forest Corp., C. Rand and S. Gilman from Mt. Riga, Inc., C. Youell, A. Hubbard and S. Rogers of the Metropolitan District Commission, Steep Rock Association and the state foresters of the Connecticut Division of Forestry, and state park managers from State Parks and Forests, Connecticut Department of Energy and Environmental Protection for their support and permission for property access.*
- *R. Cowles, F. Ferrandino, Michael Wininger for valuable statistical advice*
- *Special thanks to Dr. Louis Magnarelli for his support throughout.*
- *Funding for HWA research was from the USDA Forest Service, Northeastern Area State and Private Forestry 2000-2009 and from the National Institute for Food and Agriculture, McIntire-Stennis Cooperative Forestry Research Program 2013 -2018.*

USDA

United States Department of Agriculture

National Institute of Food and Agriculture

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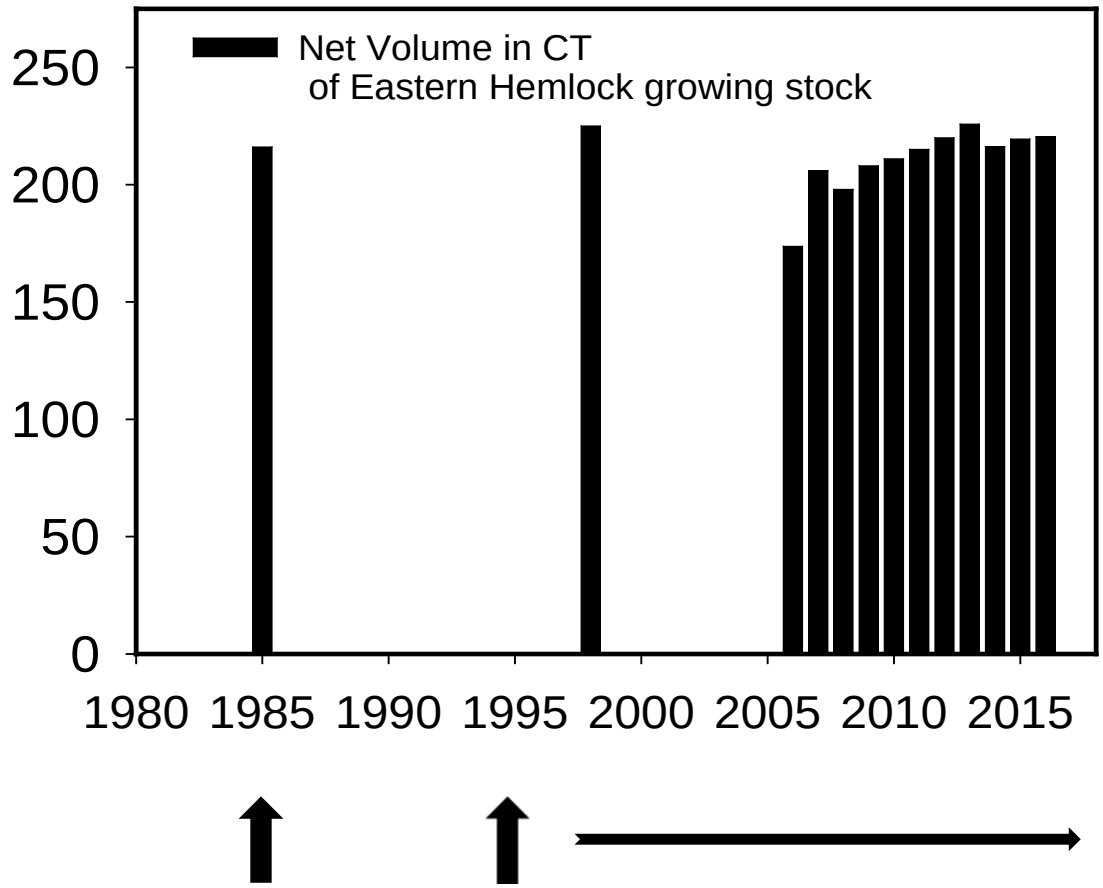
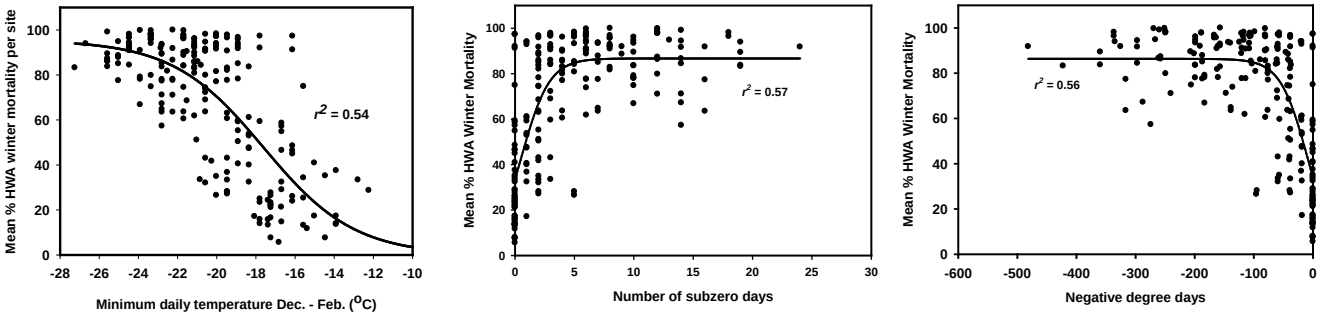
Addendum

Status of CT's hemlocks

Volume of live hemlock on CT forest land (million cubic ft)



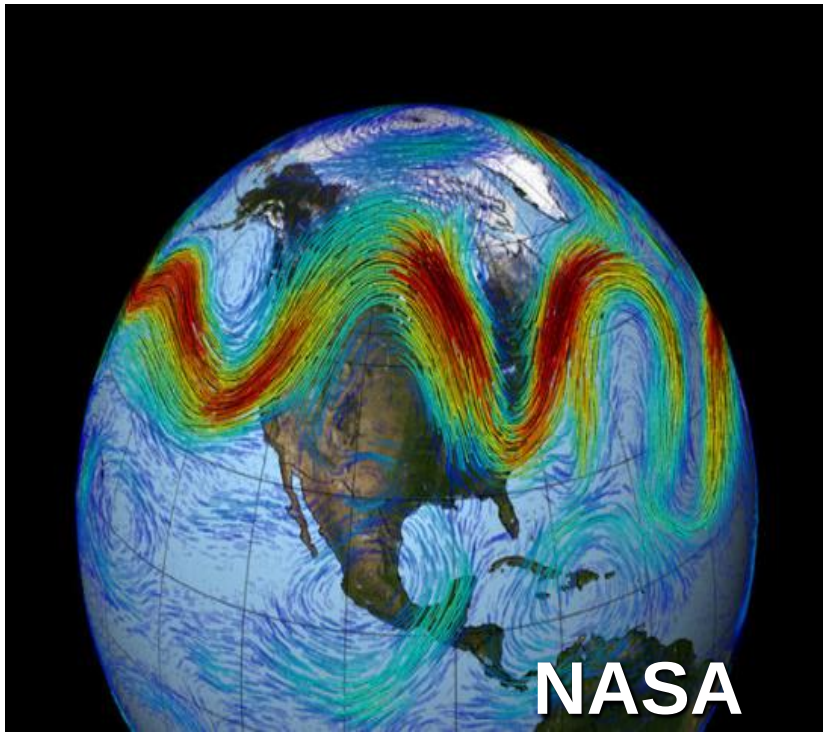
Important Determinants of HWA Winter Mortality in CT



- Minimum daily winter temperature (December through February): this is the best predictor
- Number of subzero days (Base is 0°F or -17.8°C)
- Duration and intensity of subzero cold, expressed as Negative Degree Days or NDD
- NDD is a new concept derived from this CT study

ARCTIC AMPLIFICATION

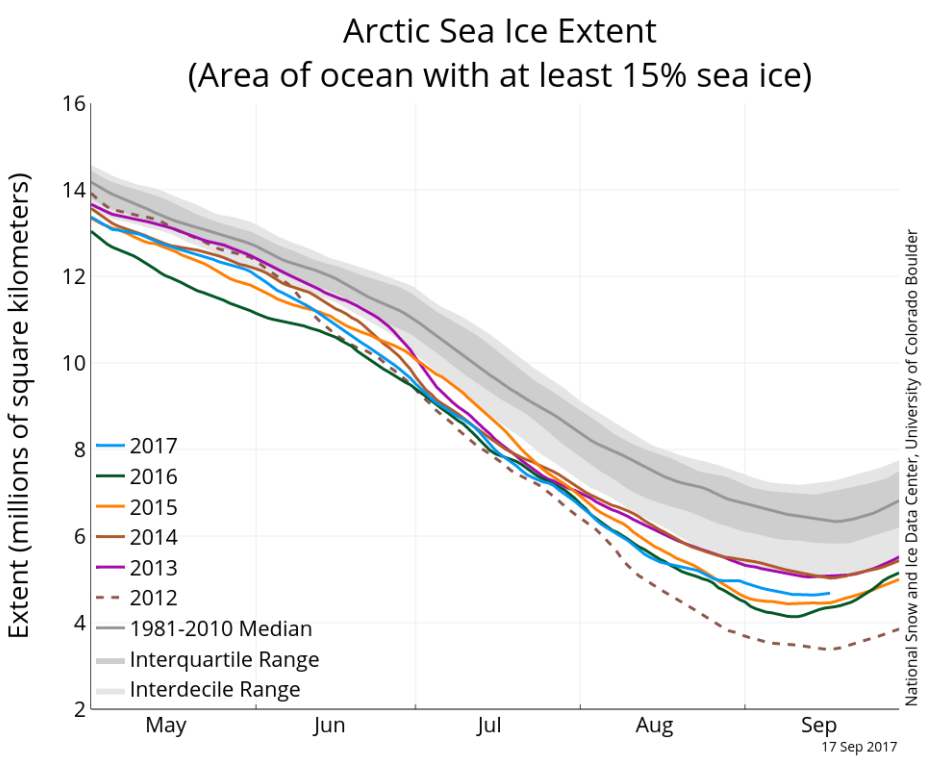
- Arctic sea ice cover is declining at unprecedented rates
- The Arctic is warming at 2x global rate due to a positive feedback loop
- Enhanced Arctic warming may also be fueling extreme cold weather in the mid and lower latitudes by weakening the polar vortex
- Unpredictable outbreaks of extreme arctic air are becoming more frequent during Northeast winters……

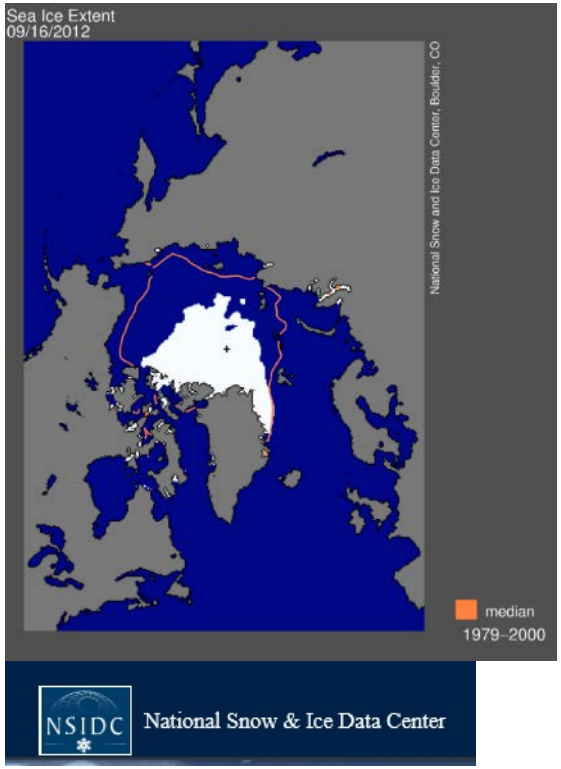


This may cause **greater instability of the jet stream,** allowing **more intrusions of polar air** into the lower latitudes during warmer Arctic winters.

Arctic warming and sea ice loss influences extreme weather in mid-latitudes

Arctic Sea Ice Extent at its Minimum in September





Arctic Sea Ice Extent at its Maximum in March