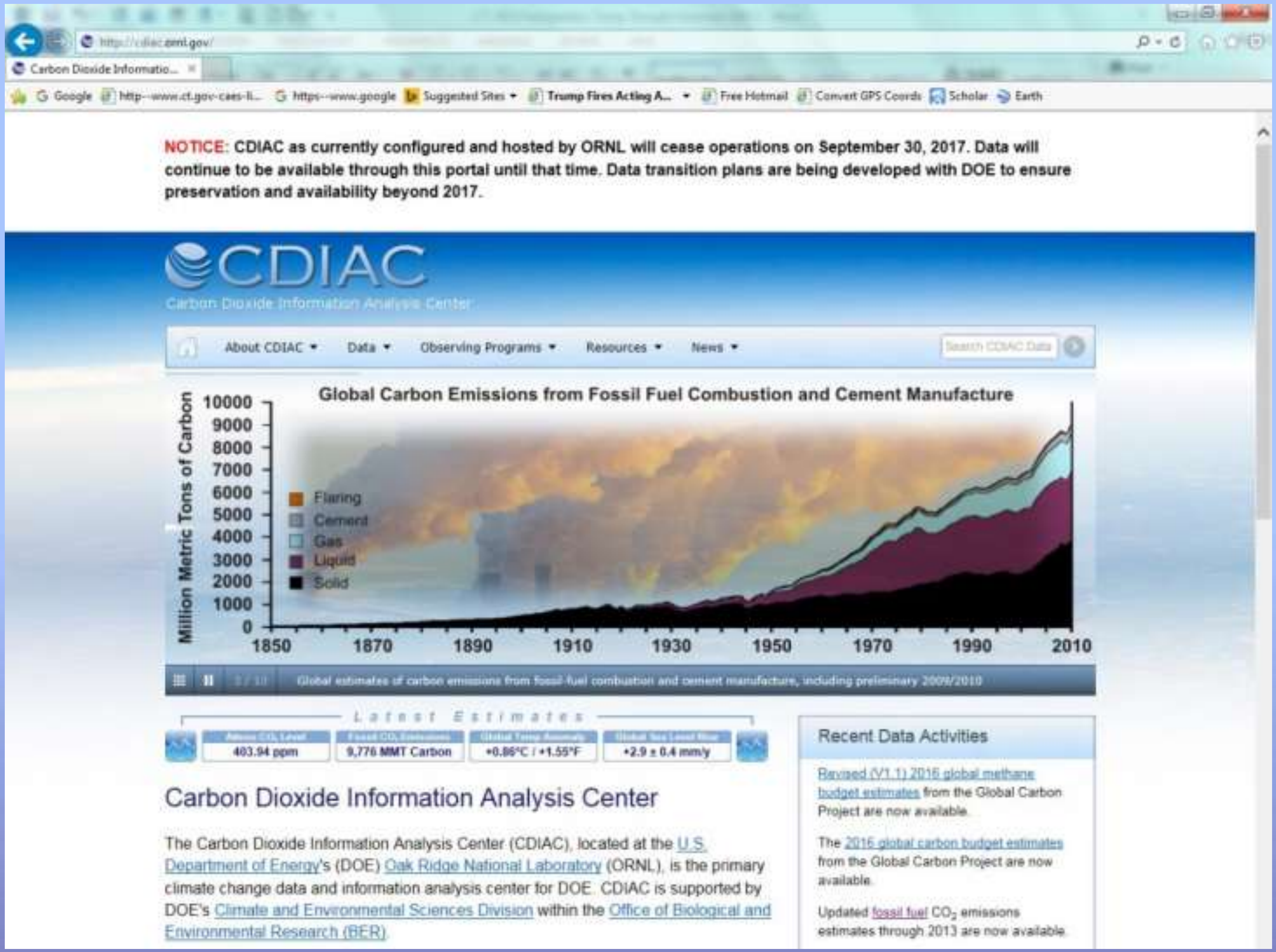
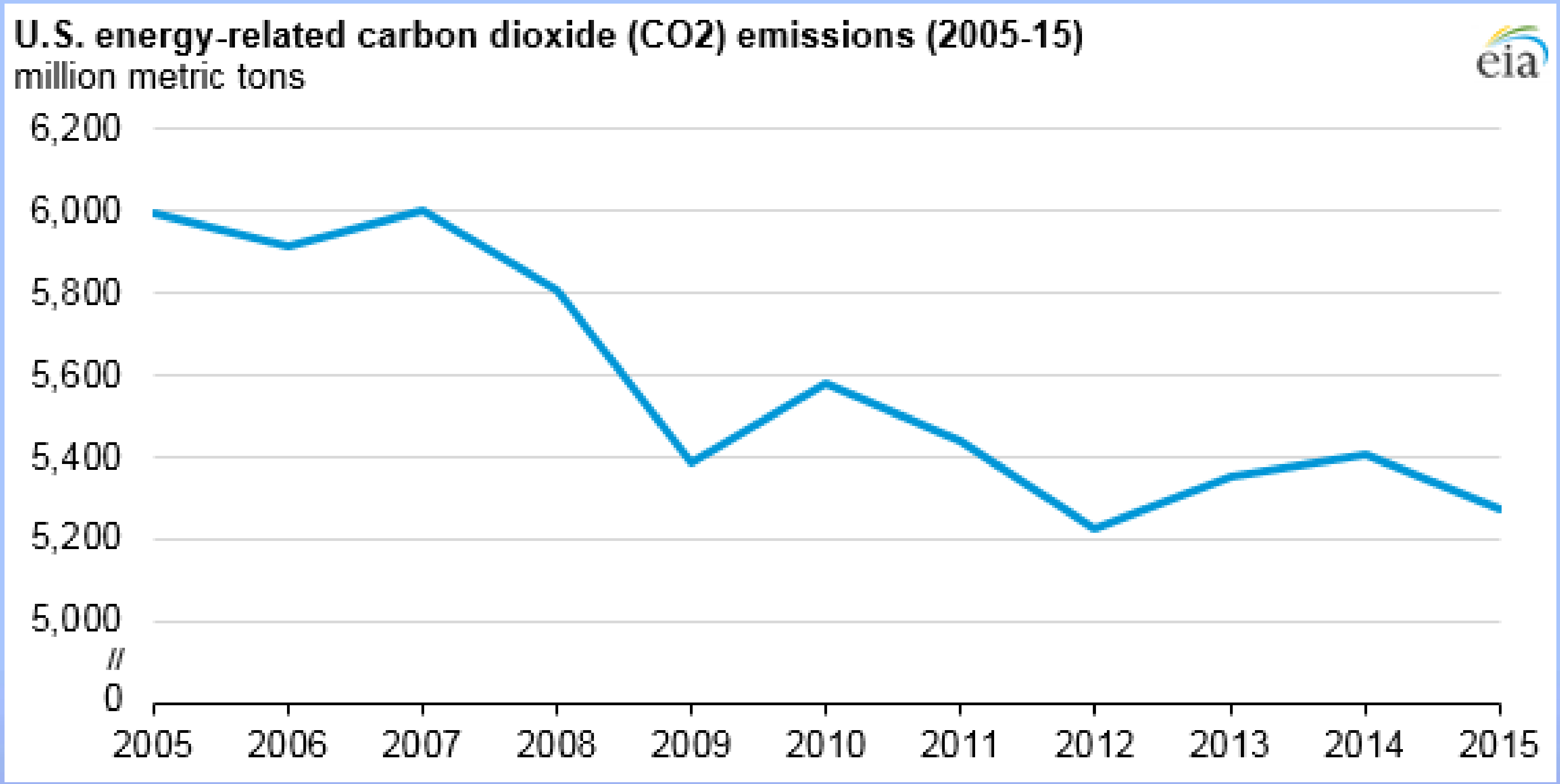
Climate Change
Implications for Biological Control of Hemlock Woolly Adelgid & Mile-a-Minute Weed




Carole Cheah
Valley Laboratory
The Connecticut Agricultural Experiment Station

Vital U.S. Government environmental monitoring and analysis: Will important data and unbiased analysis still be available to the public?

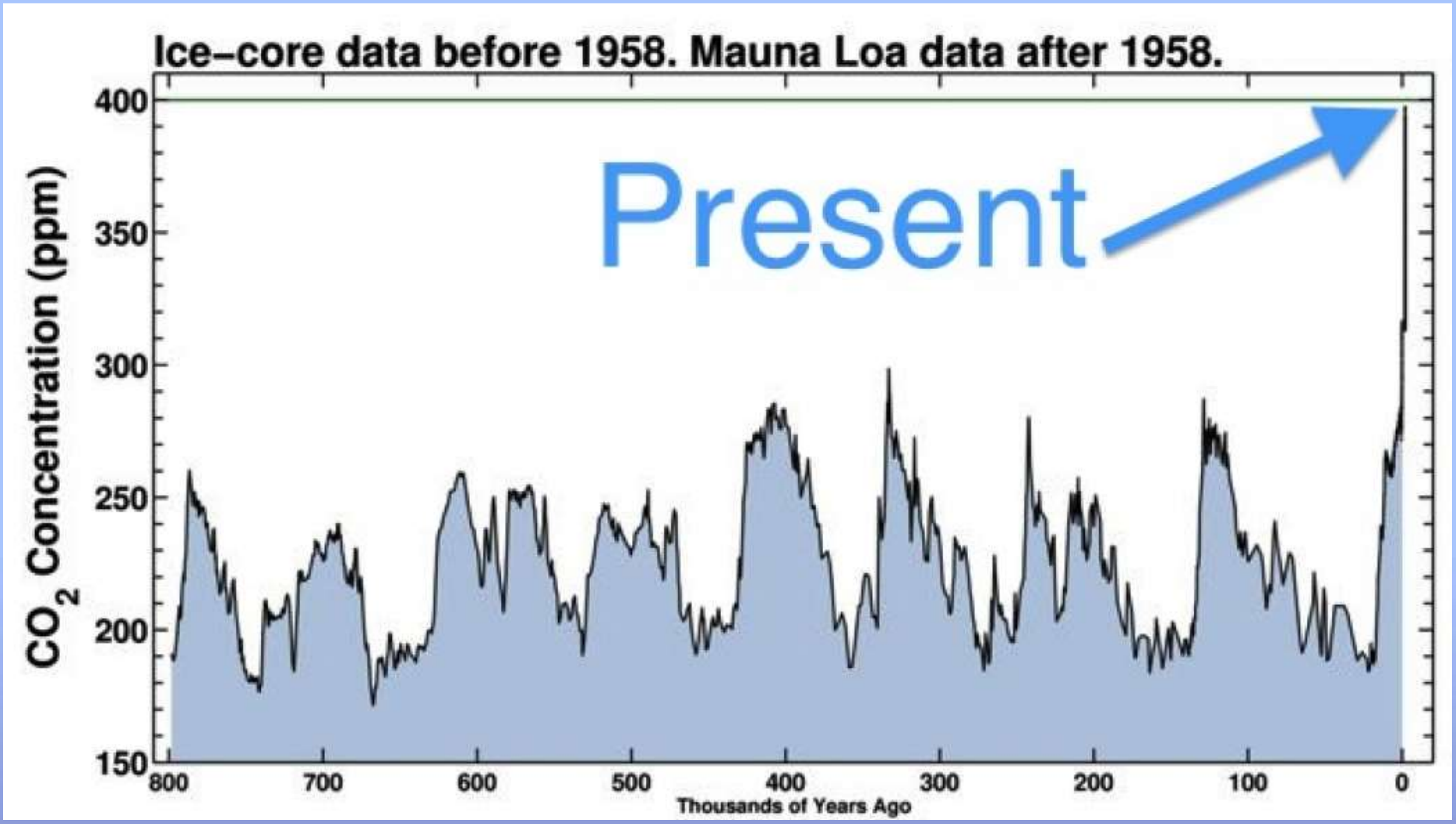




Source: US Energy Information Administration; Monthly Energy Review

On the right track…..
but for how long?

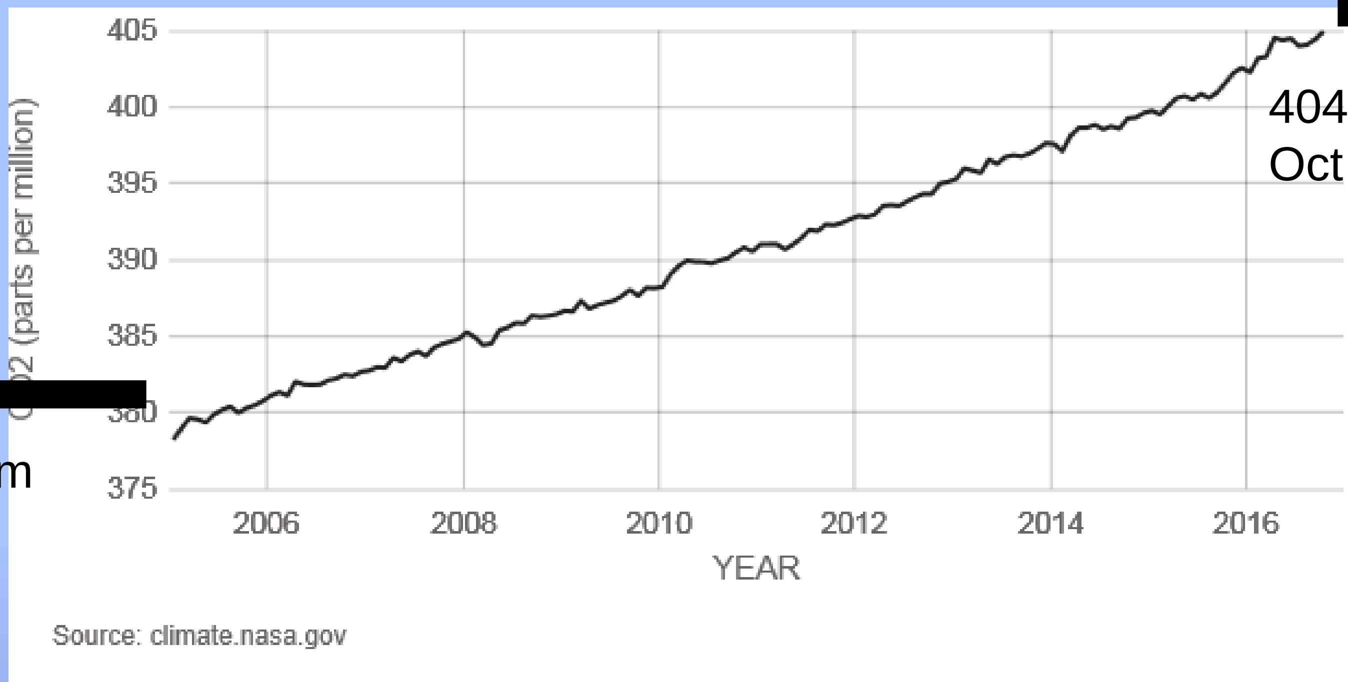
History of CO_2 global emissions



From Scripps Institute of Oceanography

Global volcanic CO_2 = <1% of annual global fossil fuel CO_2

Global CO_2 Emissions

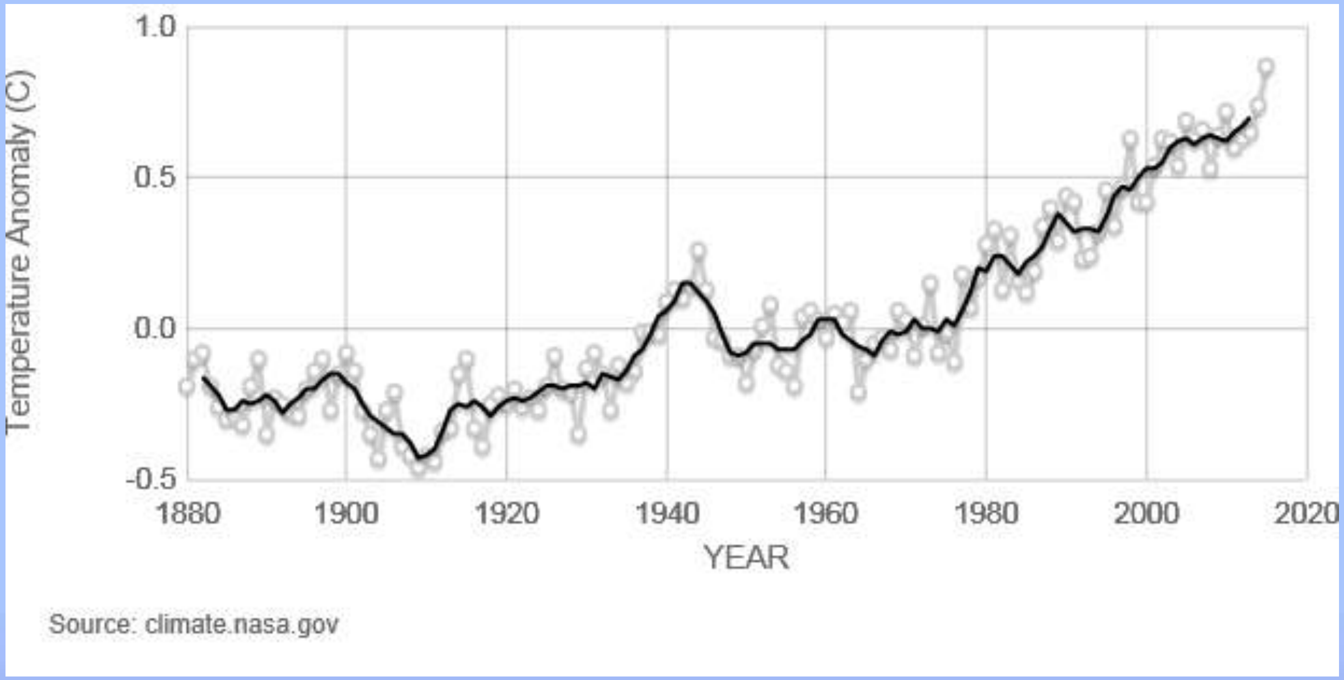


404.93 ppm
Oct 2016

378.21 ppm
Jan 2005

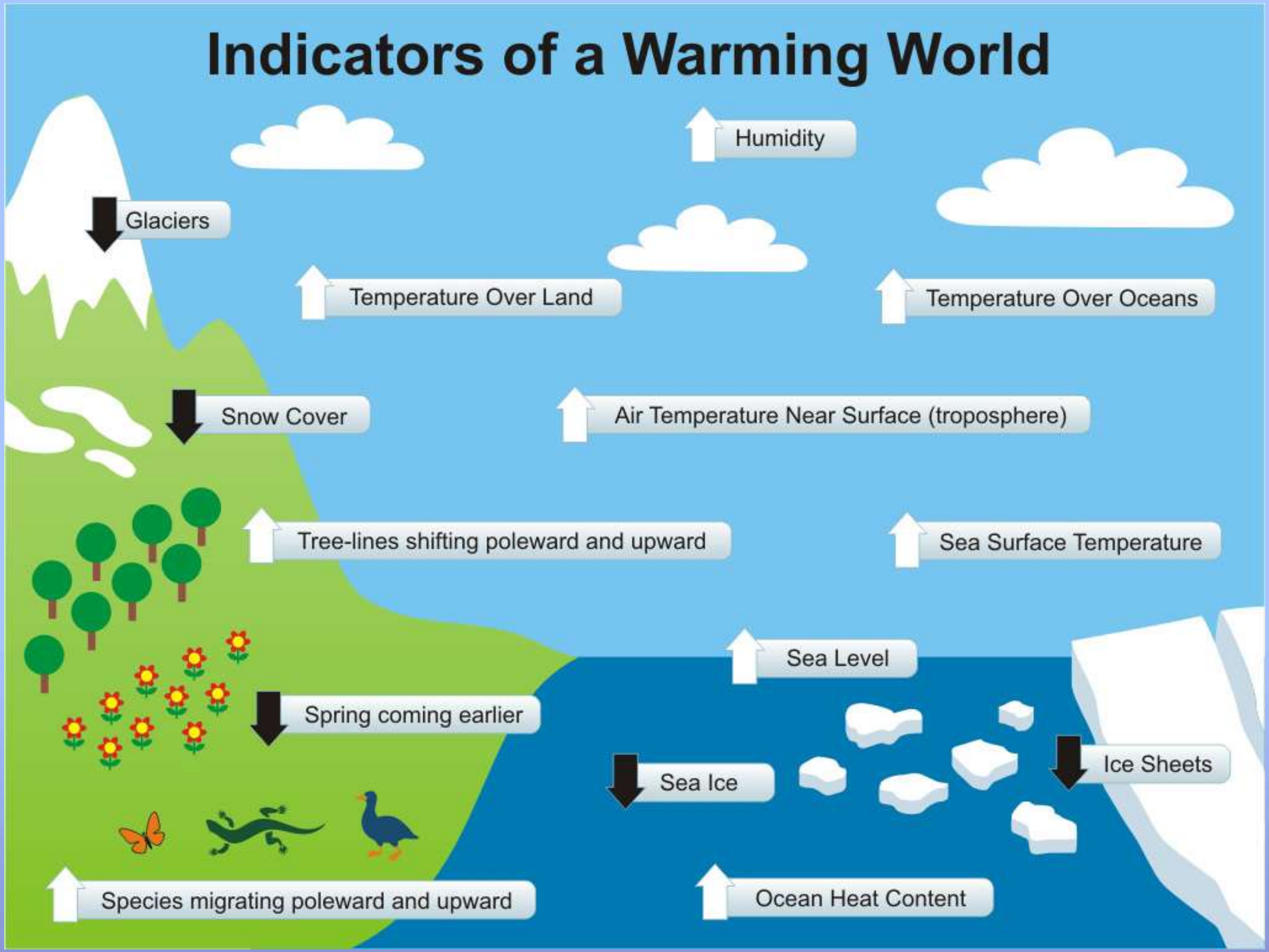
These changes are attributed largely to the increased global use of fossil fuels which have led to ever rising levels of CO_2 in the atmosphere.

Global warming trends



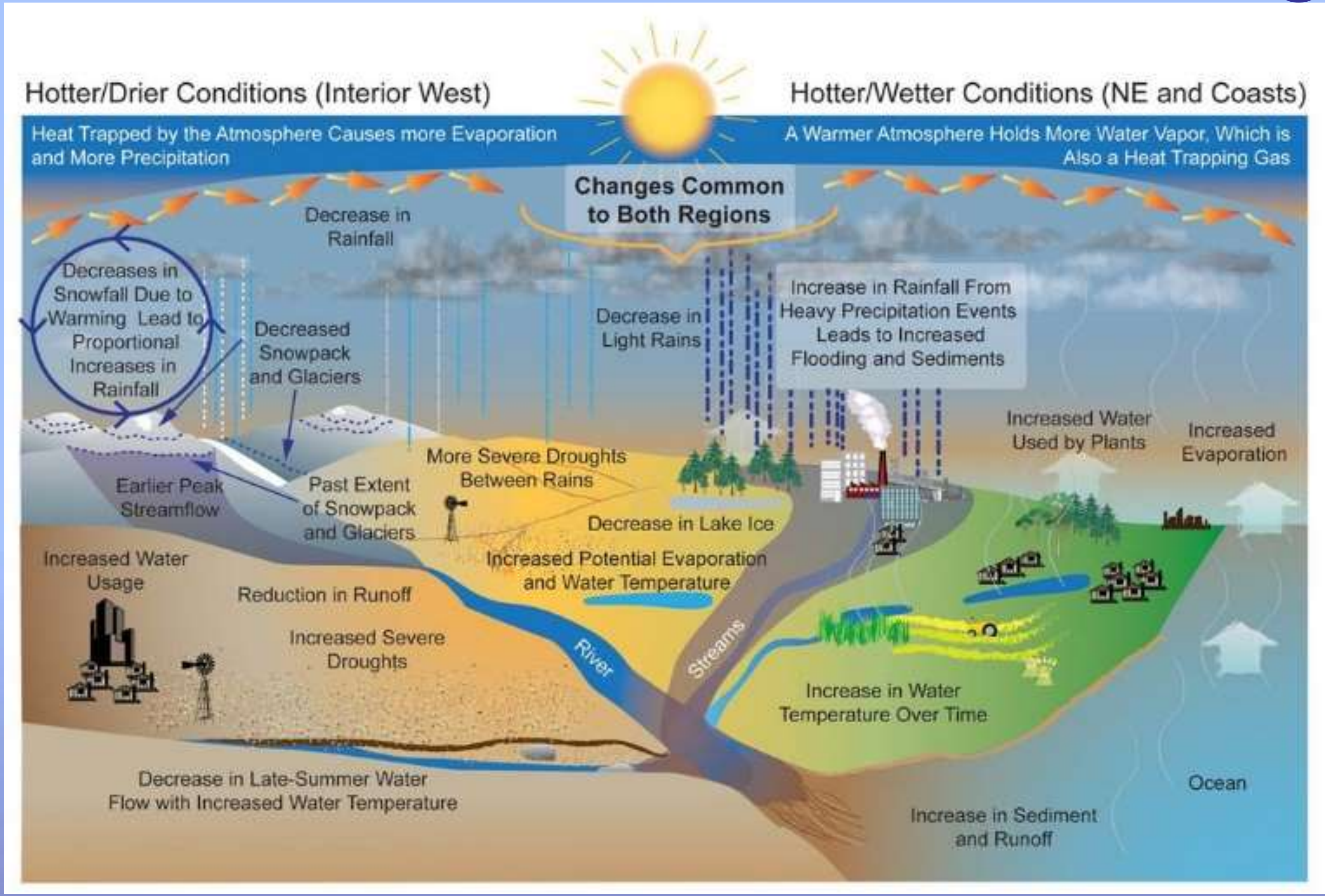
2015 Global Temperature Increase: 0.87ºC (1.57ºF)

Global land-ocean temperature index from NASA/GISS
The Goddard Institute for Space Studies



https://static.skepticalscience.com/graphics/Warming_Indicators_1024.jpg

Increased rainfall and flooding

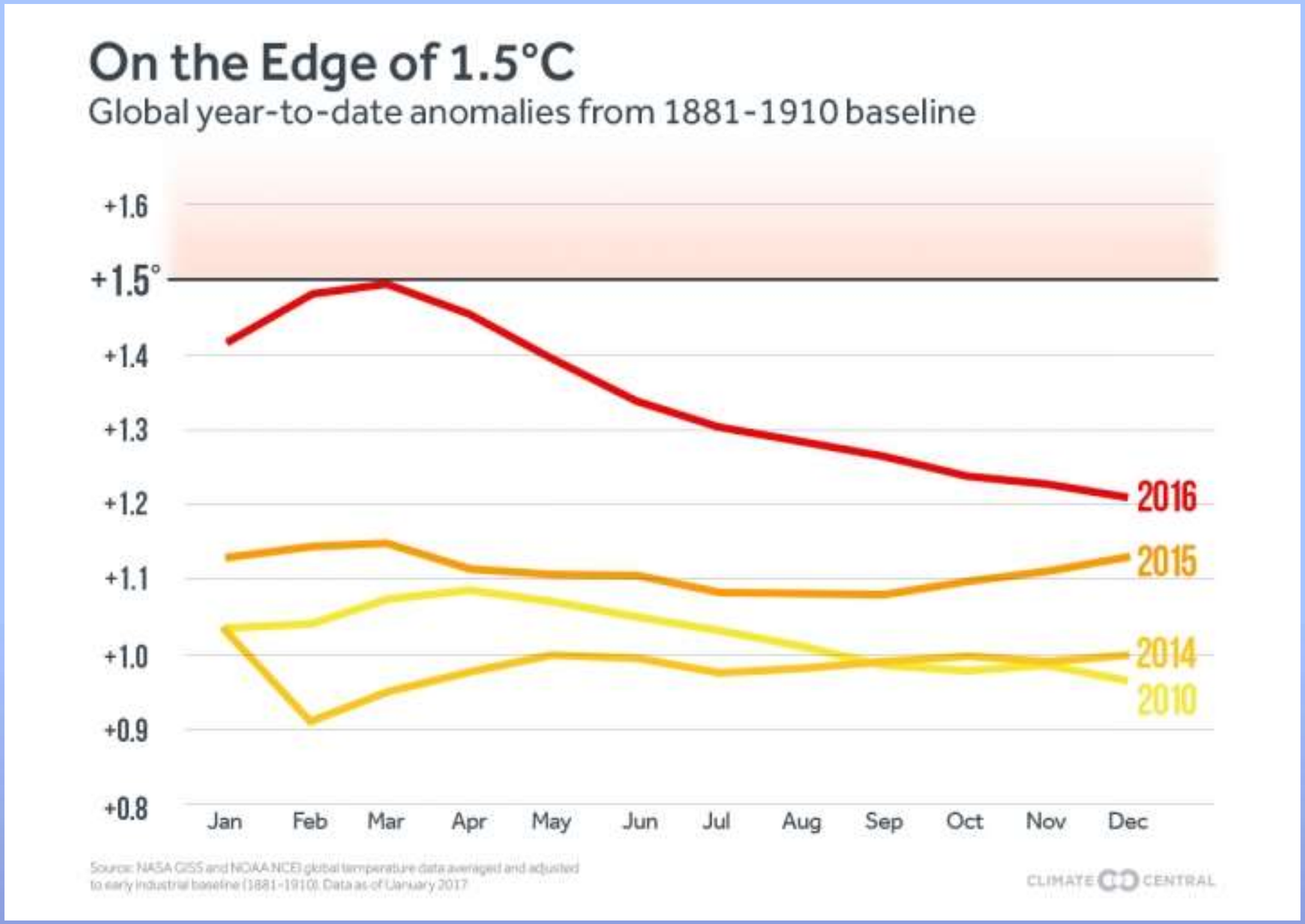


www.epa.gov

Extreme and unpredictable weather

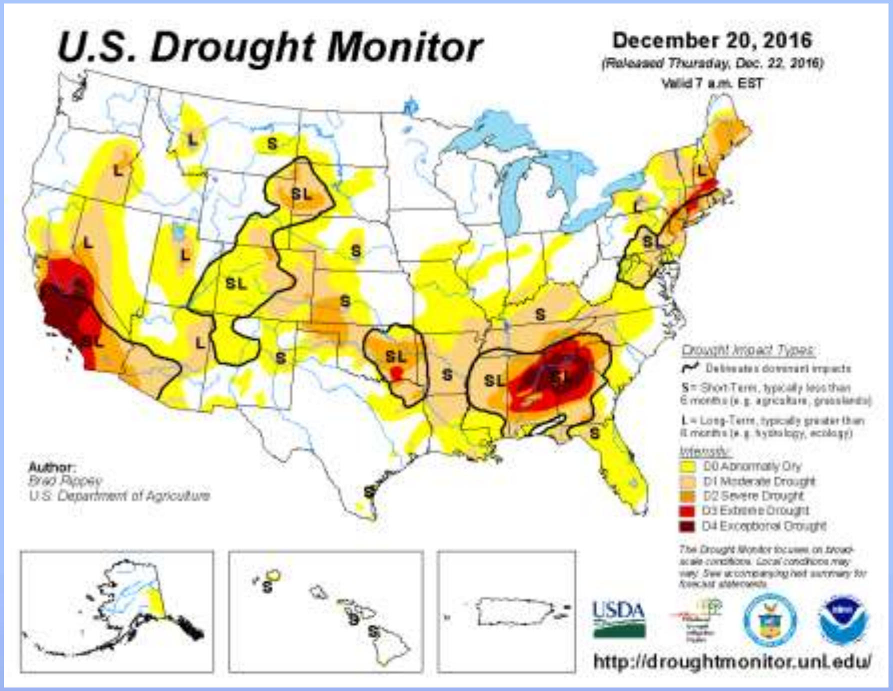
Spring 2007 Nor'easter Flooding

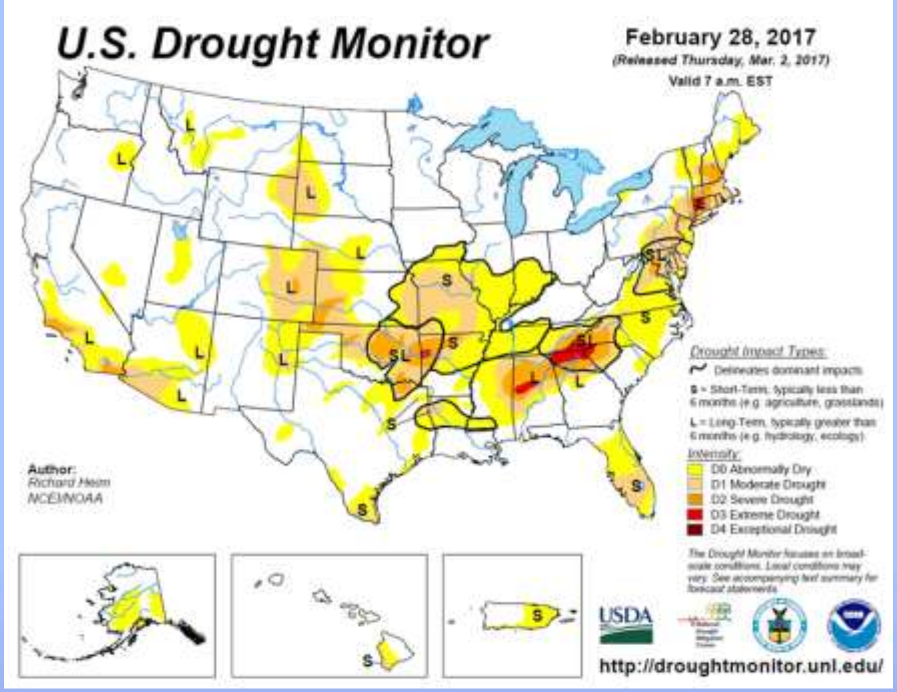
2016: the world's hottest year since records began 137 years ago



For Connecticut, 2016 was the second warmest year since 1895; the warmest year was 2012; rankings calculated for past 122 years (NRCC)

Extreme drought in some sections

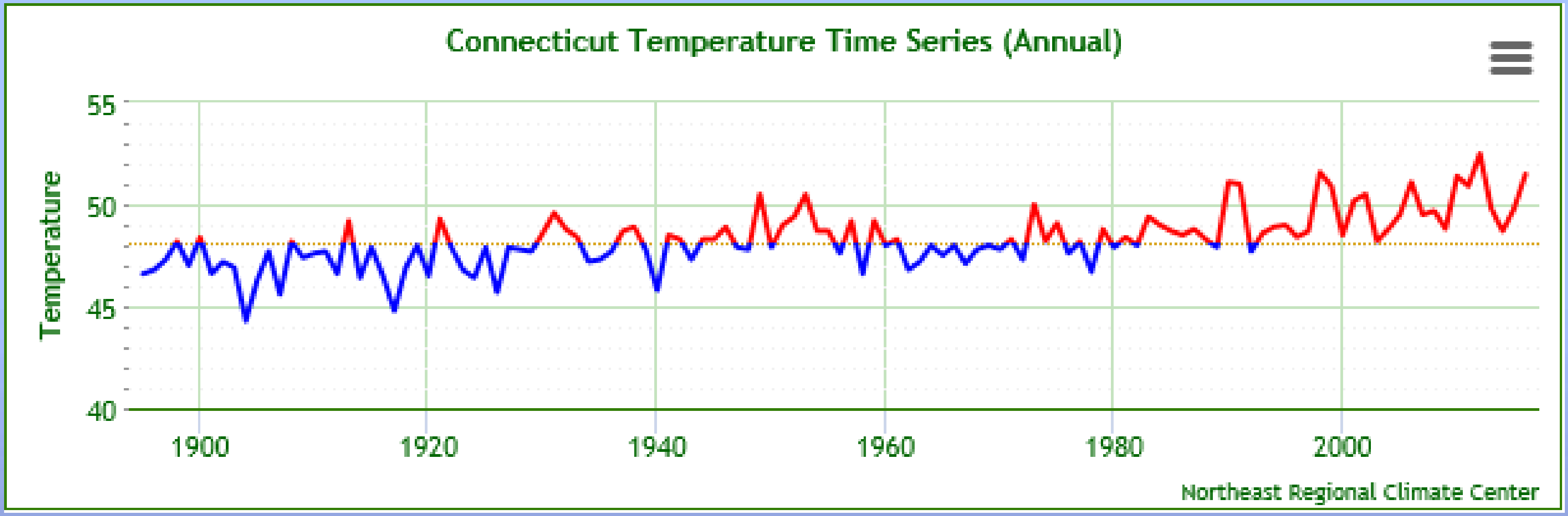




Increased frequency and duration of droughts may be linked to decreased snow pack; situation reversal on the west coast

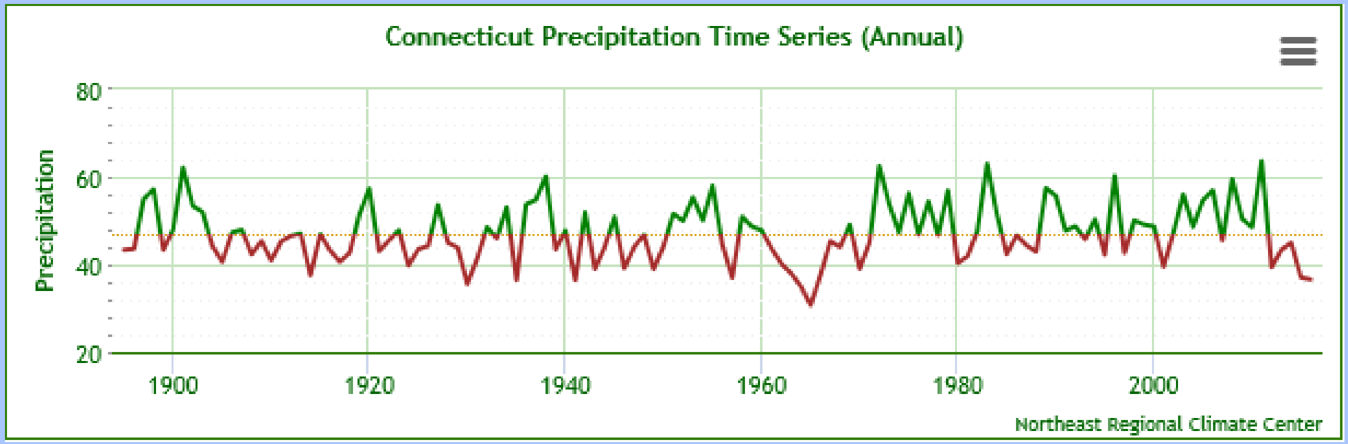
Northeast Regional Climate Center (NRCC) at Cornell

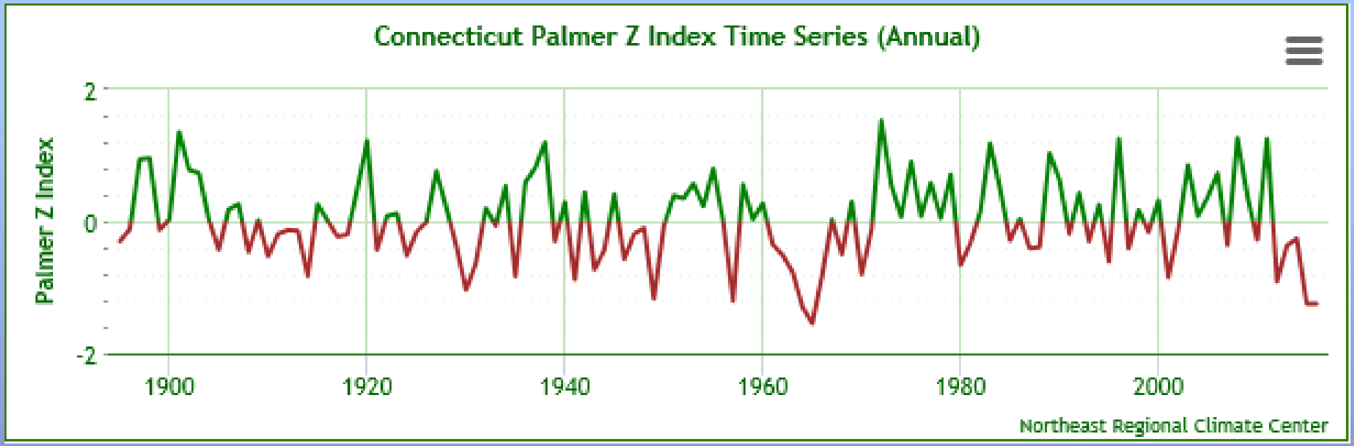
CT Annual Average Temperatures 1896-2016



Averages based on 20th Century Mean

CT Annual Precipitation and Drought 1896-2016



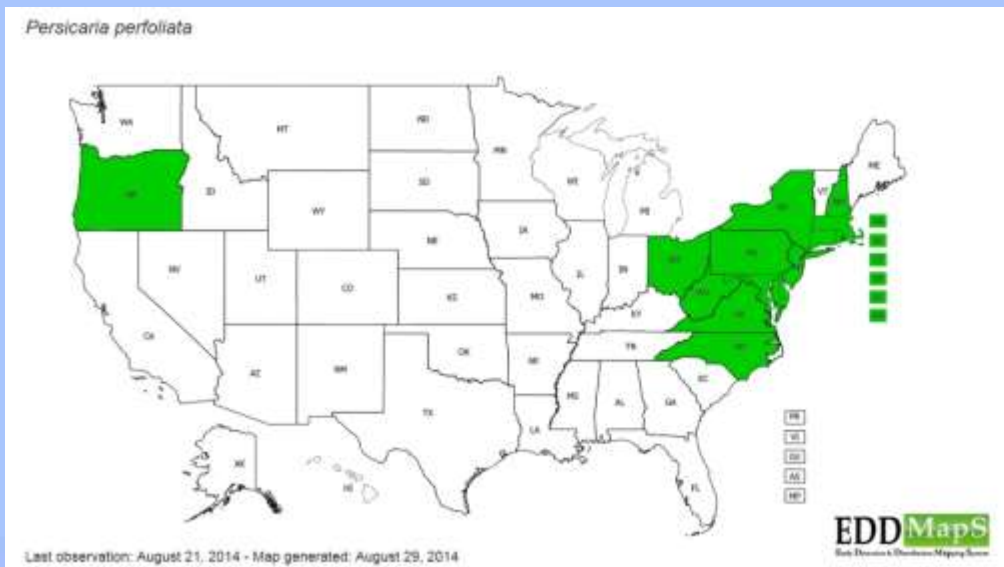


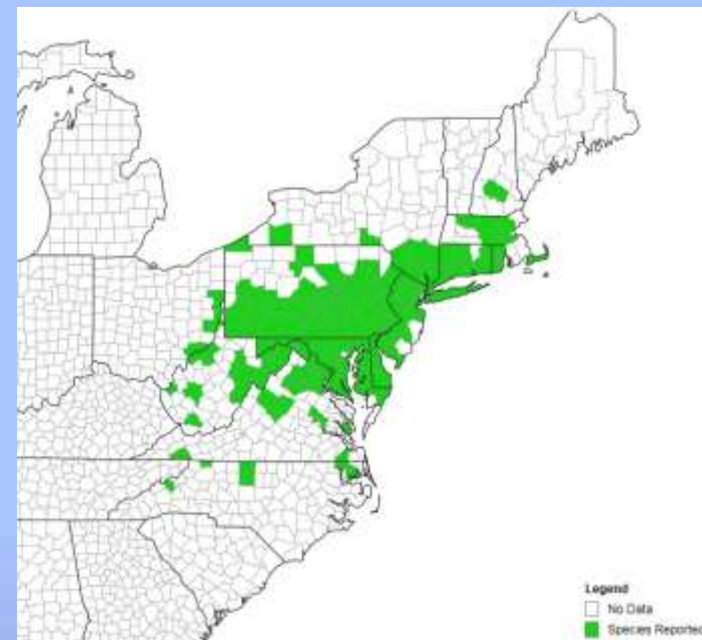
Averages based on 20th Century Mean

Mile-a-minute Weed, *Persicara perfoliatum* (Polygonaceae):

an invasive vining plant from Eastern Asia: an annual in North America, killed by frost; overwhelms native vegetation, invades edges and disturbed habitats; 1930s accidental introduction

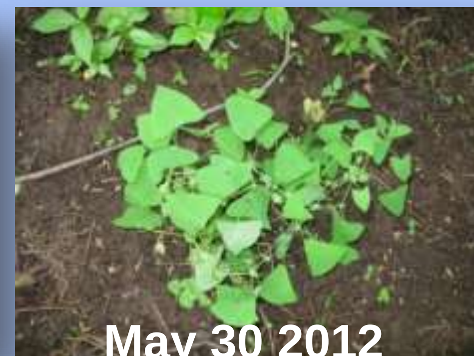
Distribution of MAM as of 2014

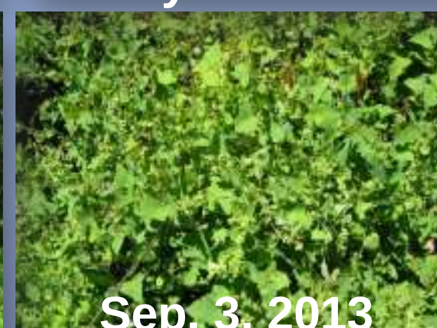


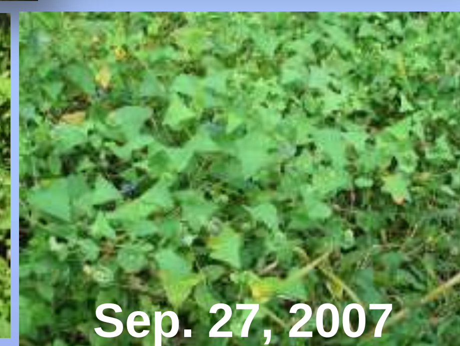


EDDMapS. 2017. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at http://www.eddmaps.org/; last accessed March 7, 2017.

Annual Growth Potential of MAM

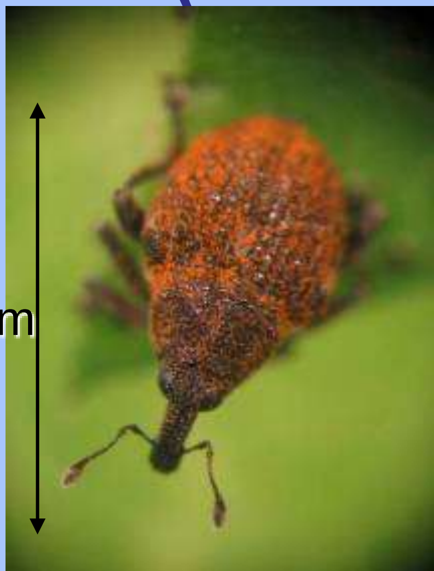


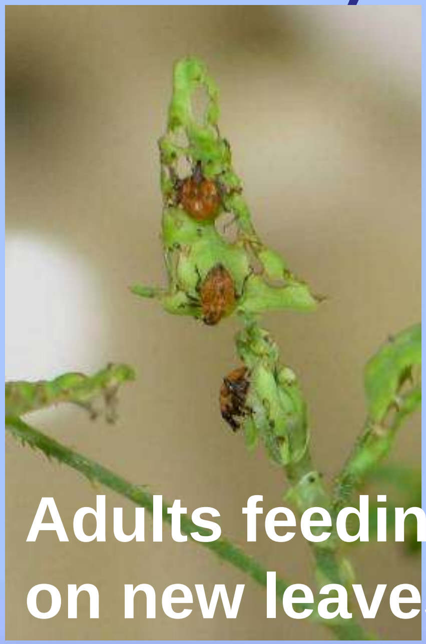




In the mid-Atlantic, in late September, 84% of immature fruit (green) were viable. In mid-August, only 35% viable (Smith et al. 2014).

Rhinoncomimus latipes (Coleoptera:Curculionidae)





Adults feeding on new leaves

Egg

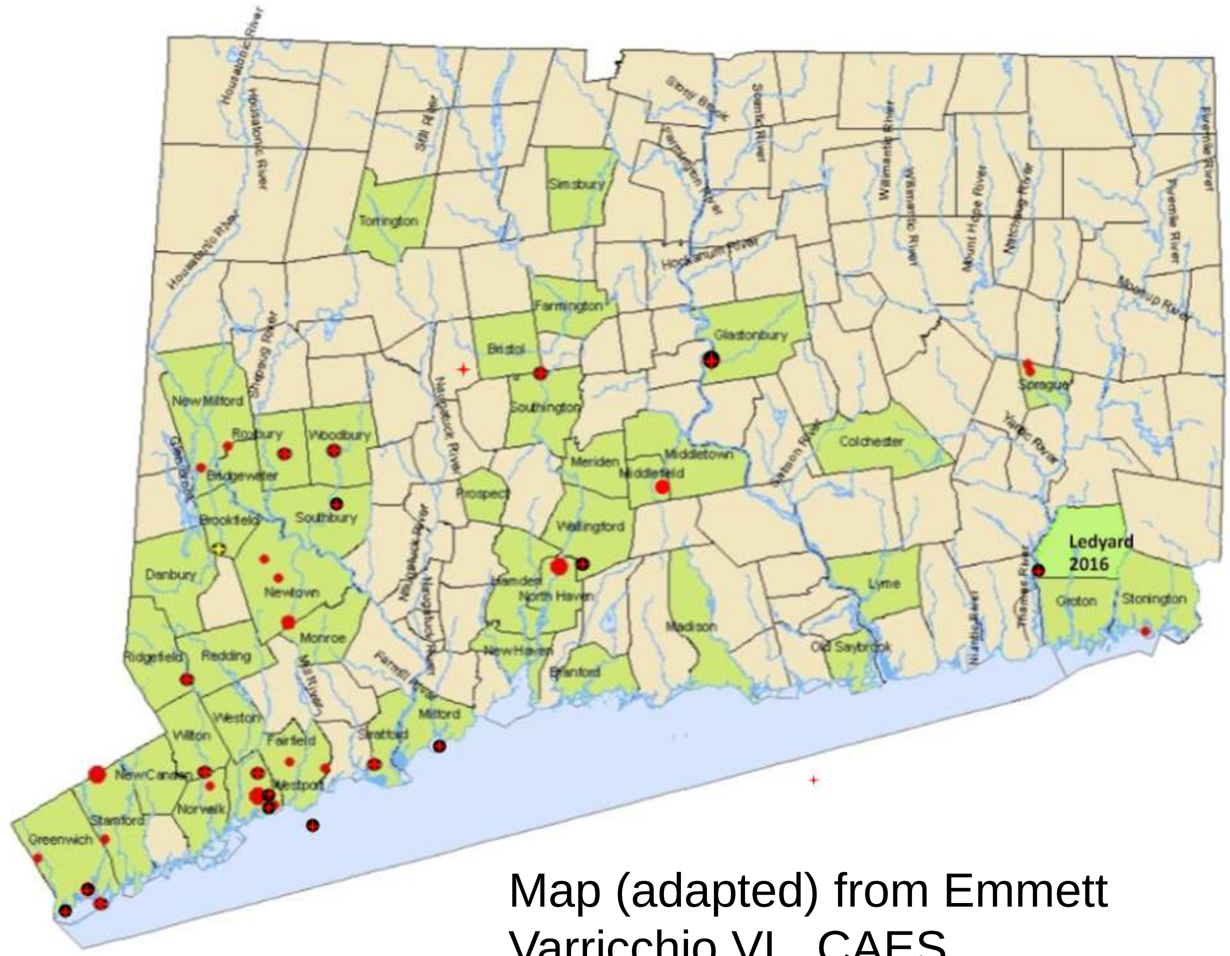
Larvae in tunnel

Biology & life cycle of *R. latipes*

- Adults are very host specific
- ♀s prefer growing tips, ♂s prefer leaves and ocreae (Colpetzer et al. 2004)
- Eggs are laid on undersides of leaves and on the stem and plant capitula of MAM
- Larvae hatch, bore into first node in stem and enter stem to feed

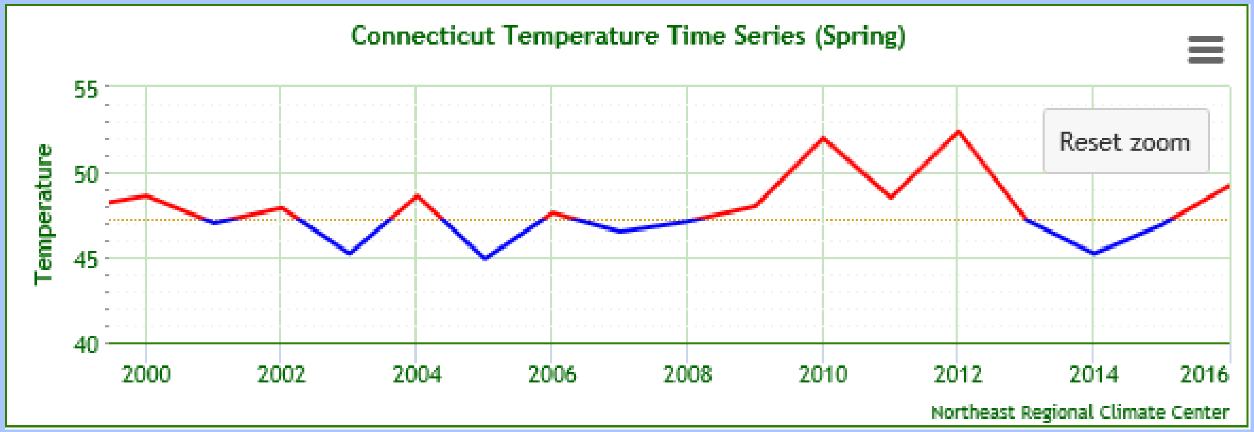
- When mature, they leave the stem and drop to soil to pupate
- New adults emerge from the soil: generation time is about 26 d; 3-4 generations in Mid-Atlantic Adults overwinter and can live about a year (Lake et al. 2011).

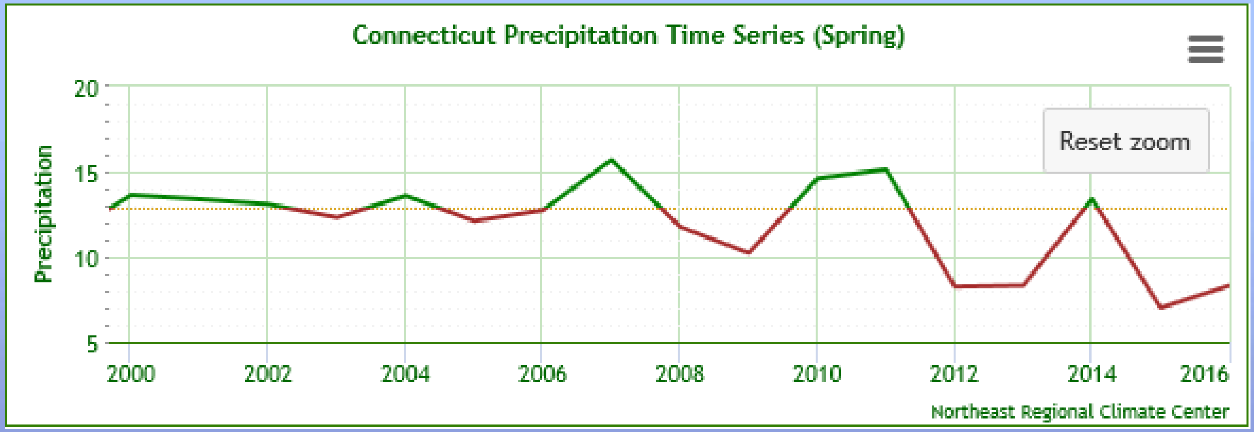
Rhinoncomimus latipes releases 2009-2016



Map (adapted) from Emmett Varricchio VL, CAES

CT Spring Temperature and Precipitation 2000-2016

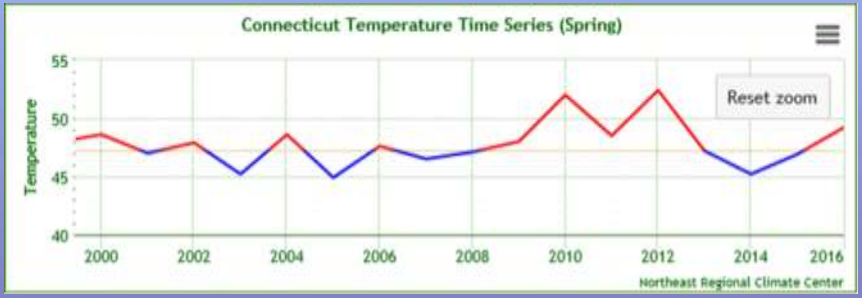




Unpredictable Springs

Using most recent 30 year (1981-2010) normal

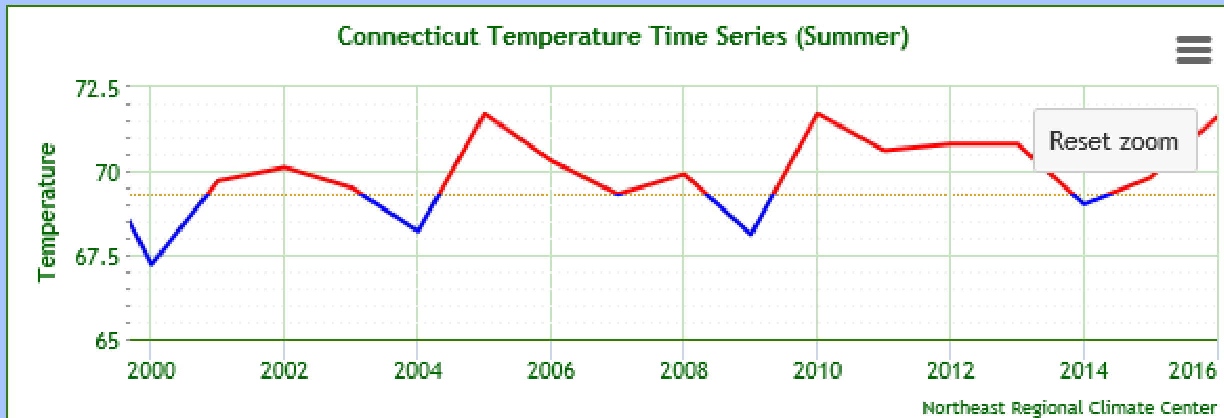
MAM has a huge seed bank that can persist for at least 6 years…

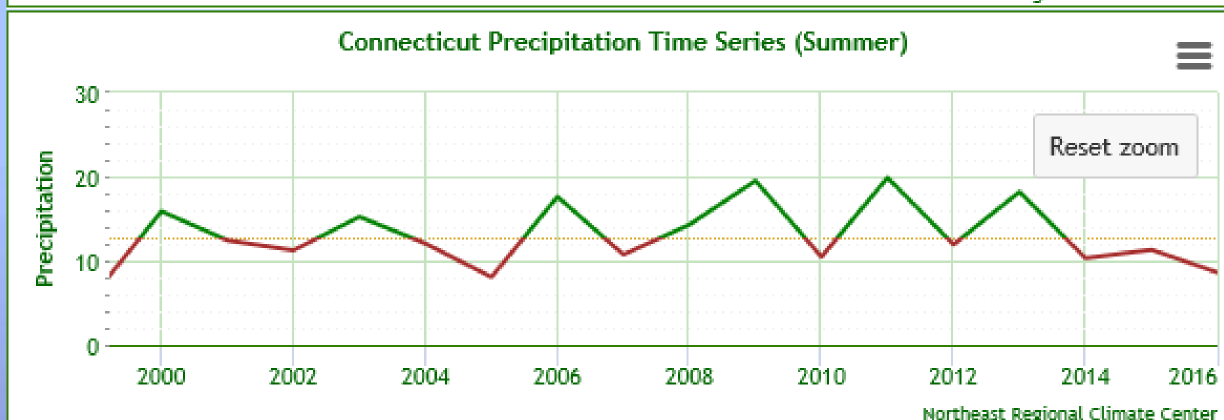


Cool, dry springs delay germination

Early warm springs accelerate germination

CT Summer Temperature and Precipitation 2000-2016





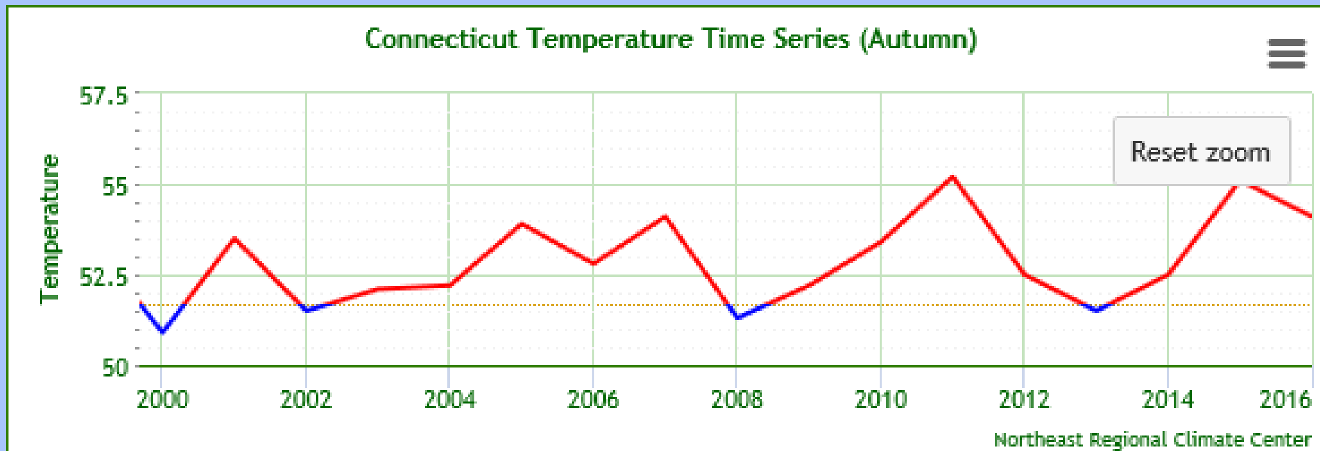
Hotter wet summers may allow faster larval development and more generations but drought may reduce larval survival (Berg et al. 2015)

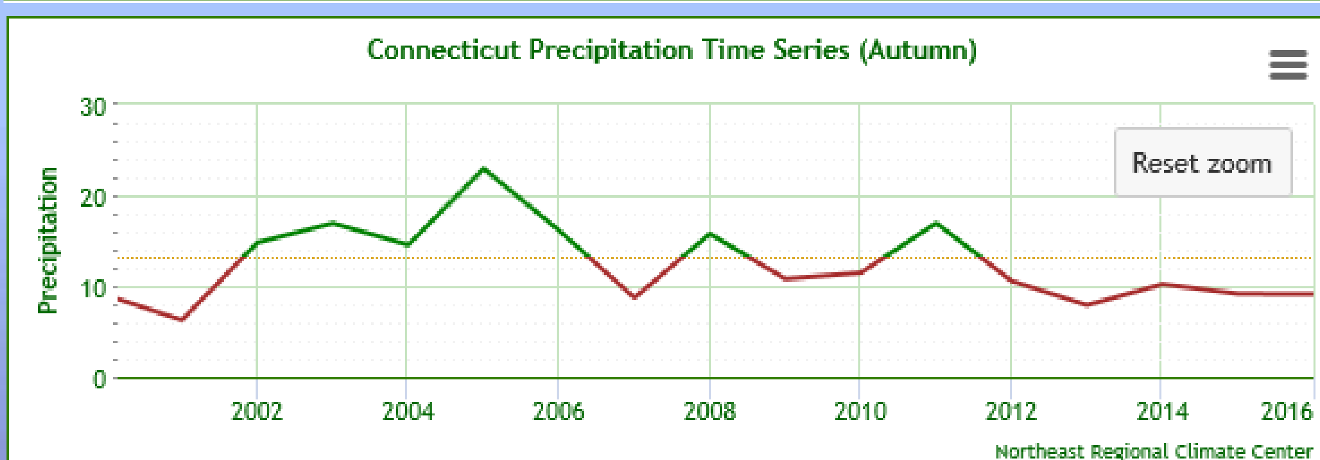
Dispersal

- Adult abundance appeared to decrease with reduced MAM growth during dry summers
- But weevils fly and are highly dispersive and can appear to rapidly colonize more nutritious patches
- Found 10-14 miles from nearest releases
- Weevils and MAM were found on islands 2-4 miles offshore



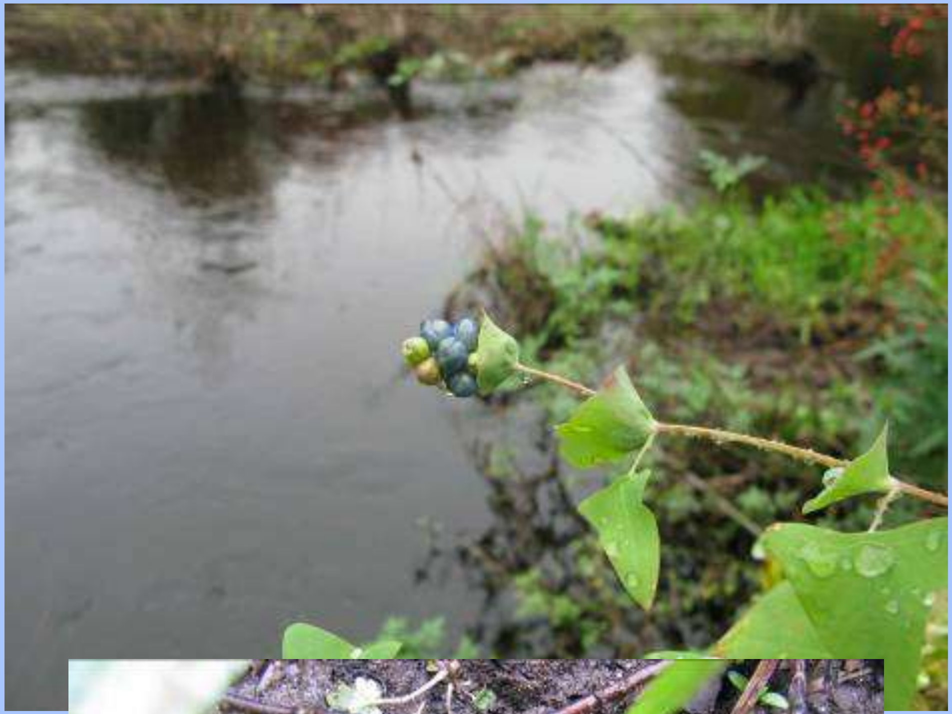

CT Autumn Temperature and Precipitation 2000-2016





Flooding from unpredictable severe storms?

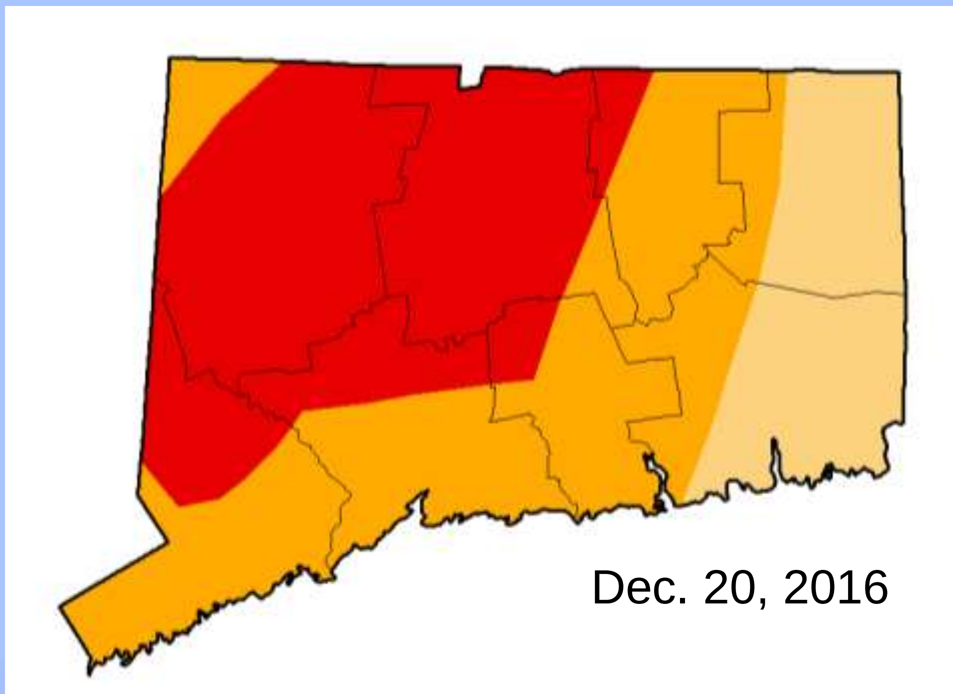
Severe storm damage and flooding in 2011



Flooding probably increases dispersal of buoyant MAM seeds

…pupating larvae in soil are drowned during prolonged floods

DROUGHT



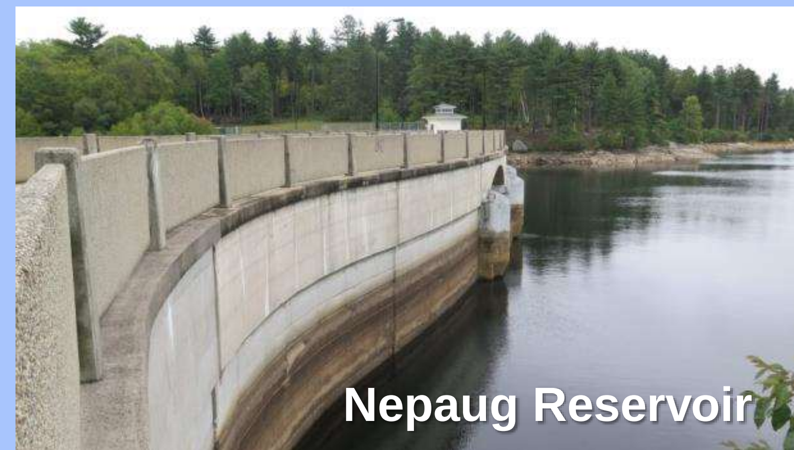
Intensity:

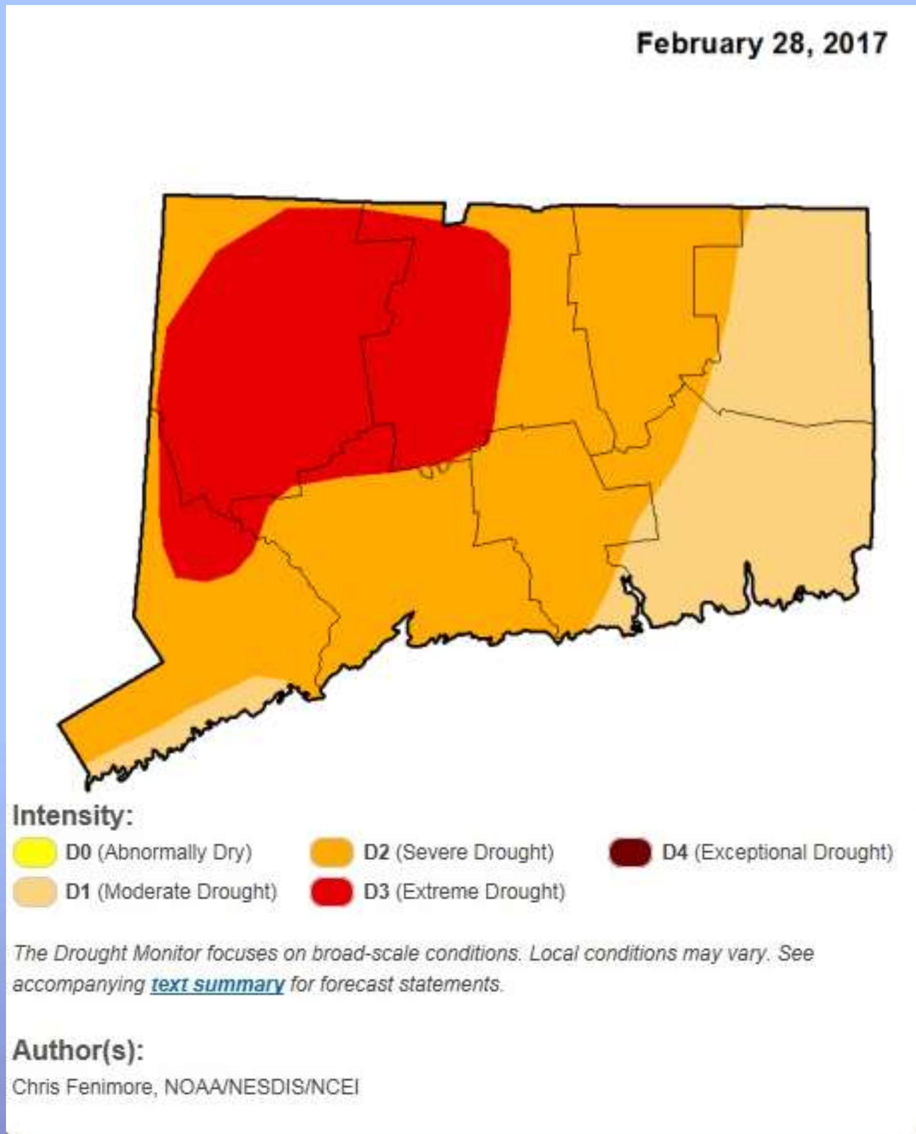
D0 (Abnormally Dry)
D1 (Moderate Drought)
D2 (Severe Drought)
D3 (Extreme Drought)
D4 (Exceptional Drought)

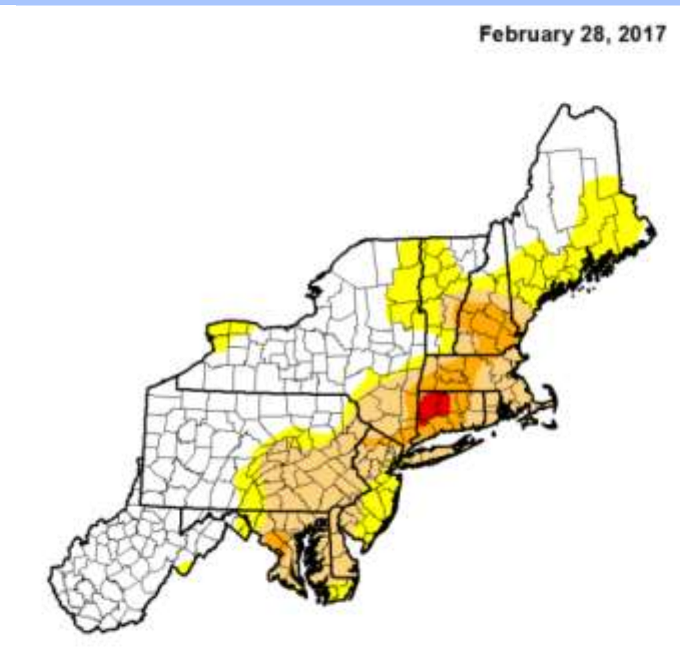
*The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying **text summary** for forecast statements.*

Author(s):

Chris Fenimore, NOAA/NESDIS/NCEI





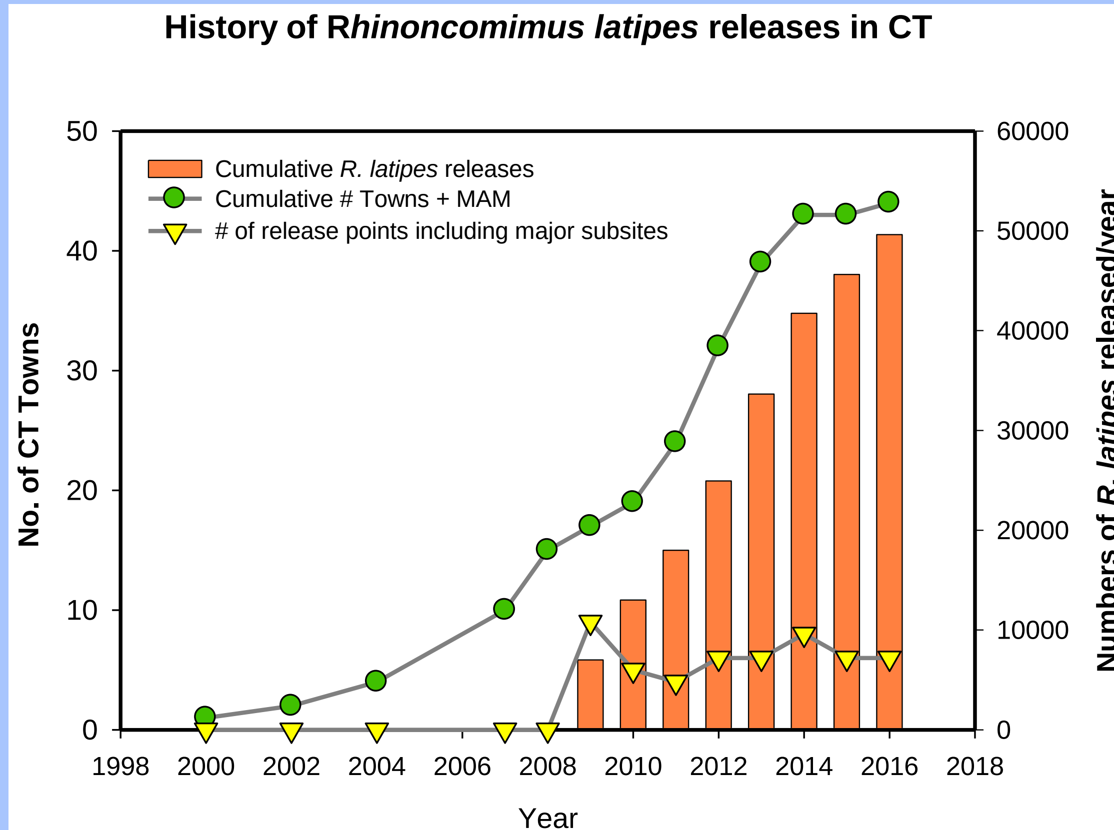


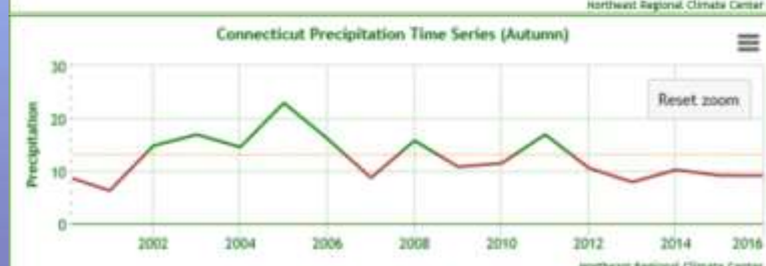
As of Feb. 28 2017, 28% of CT in extreme drought; 48% in severe drought (U.S. Drought Monitor); This current drought has been ongoing since Jan 2015

Drought impacts in 2015-2016

Majority of fruit were still immature in early fall throughout the state

Drought and herbivory may be having an impact on MAM seed production and viability (Berg et al. 2015)





What are the implications for invasive hemlock pests?

HWA= Hemlock woolly adelgid, *Adelges tsugae*

EHS = Elongate hemlock scale, *Fiorinia externa*

Damaging HWA Generations in Eastern US

Adults + Eggs

WINTER

Hatch

SPRING

PROGREDIENS

Nymphs

Winged sexuparae

Adults + Eggs

Hatch

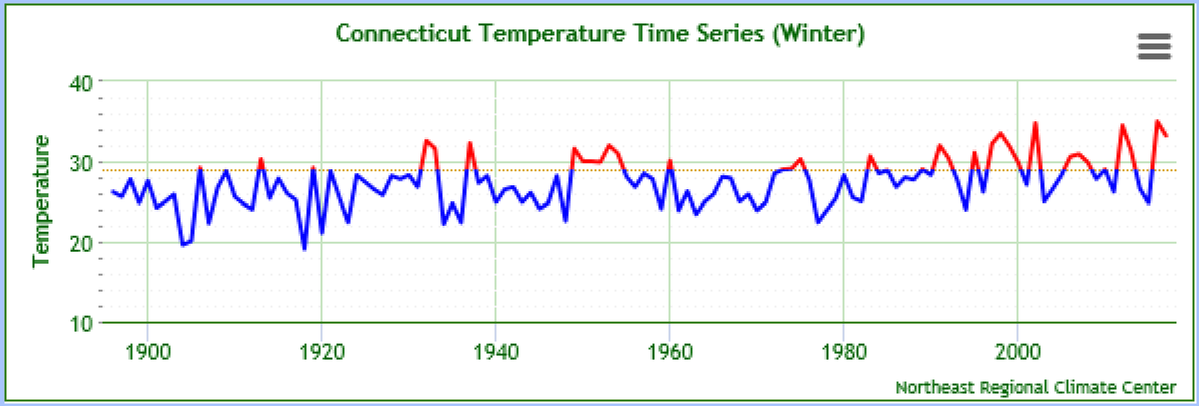
SUMMER

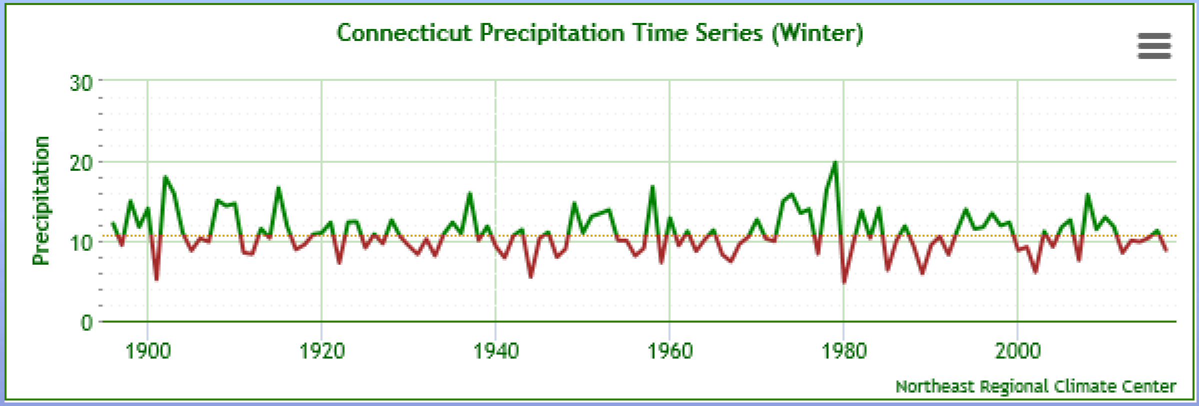
SISTENS
Summer N1 aestivation

FALL

Developing Nymphs

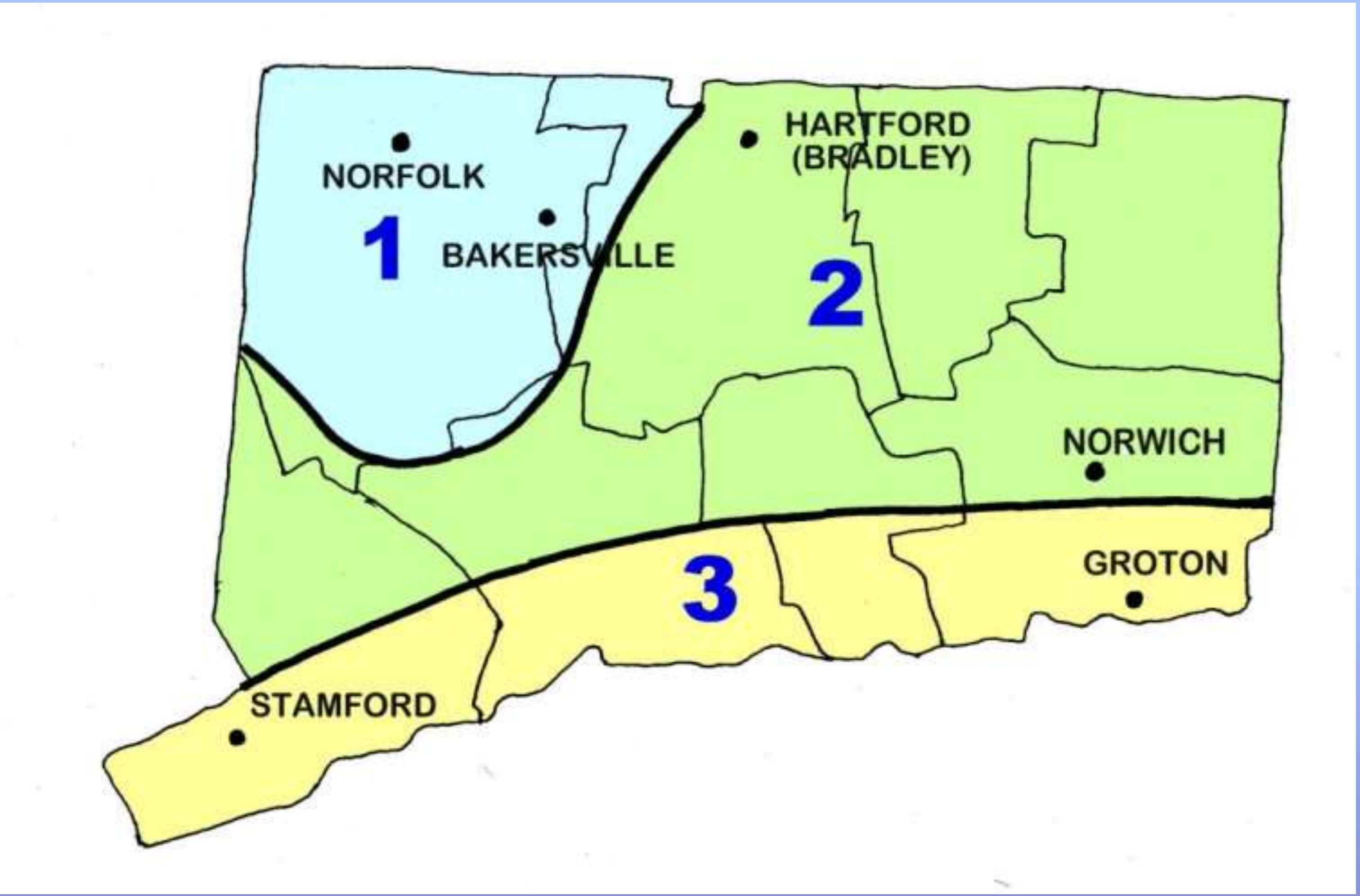
CT Winter Temperature and Precipitation Trends 2000-2017





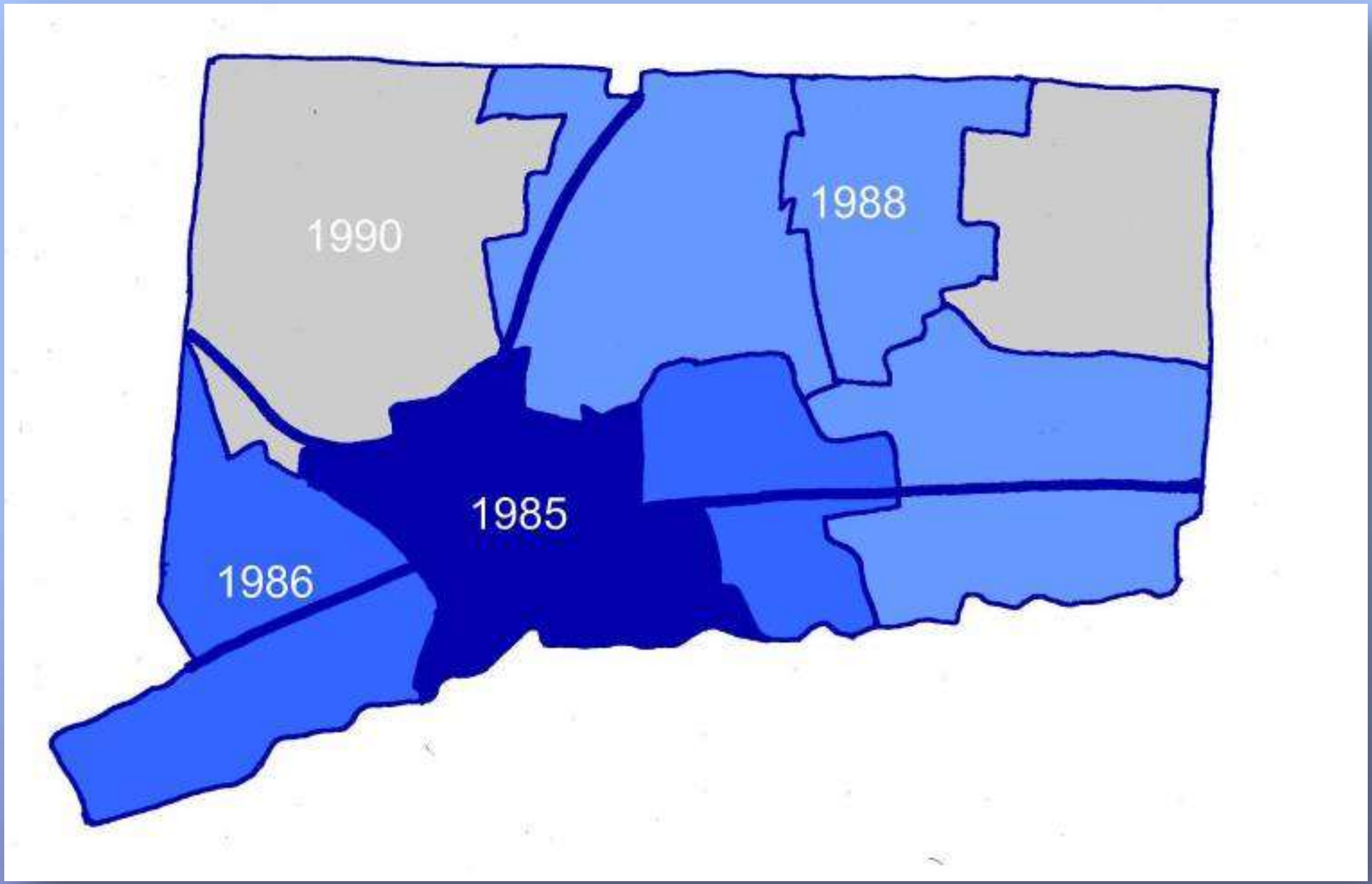
Averages based on most recent 30 year normals: 1981-2010

The 3 climatic zones of Connecticut

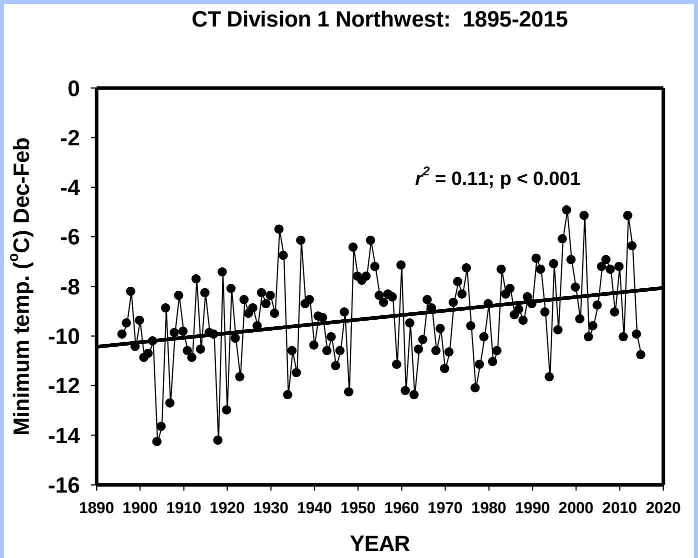


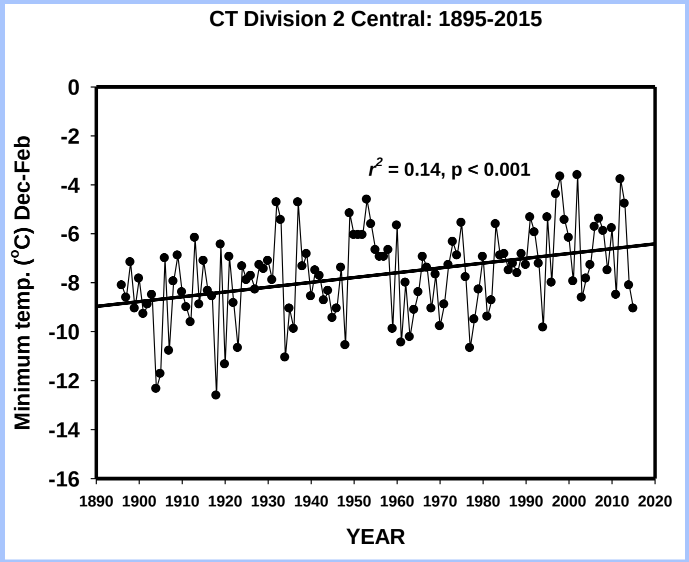
Adapted from Climatological Data of New England, NOAA

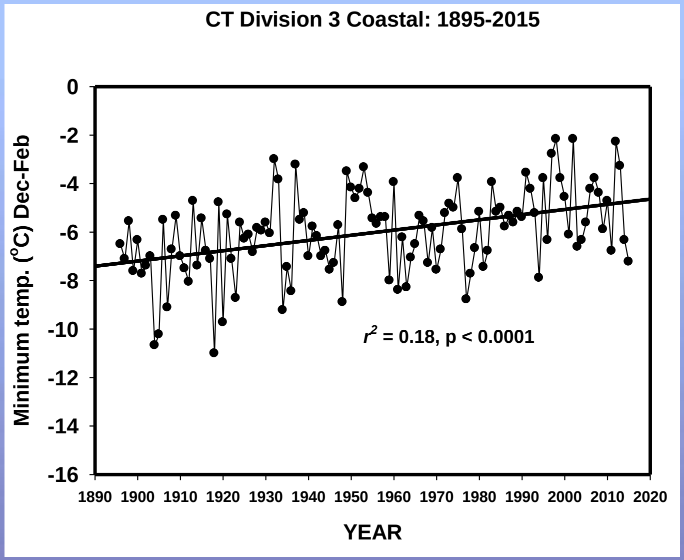
Progression of HWA in CT



The significant rise in minimum winter temperatures in CT climate divisions from 1895-2015

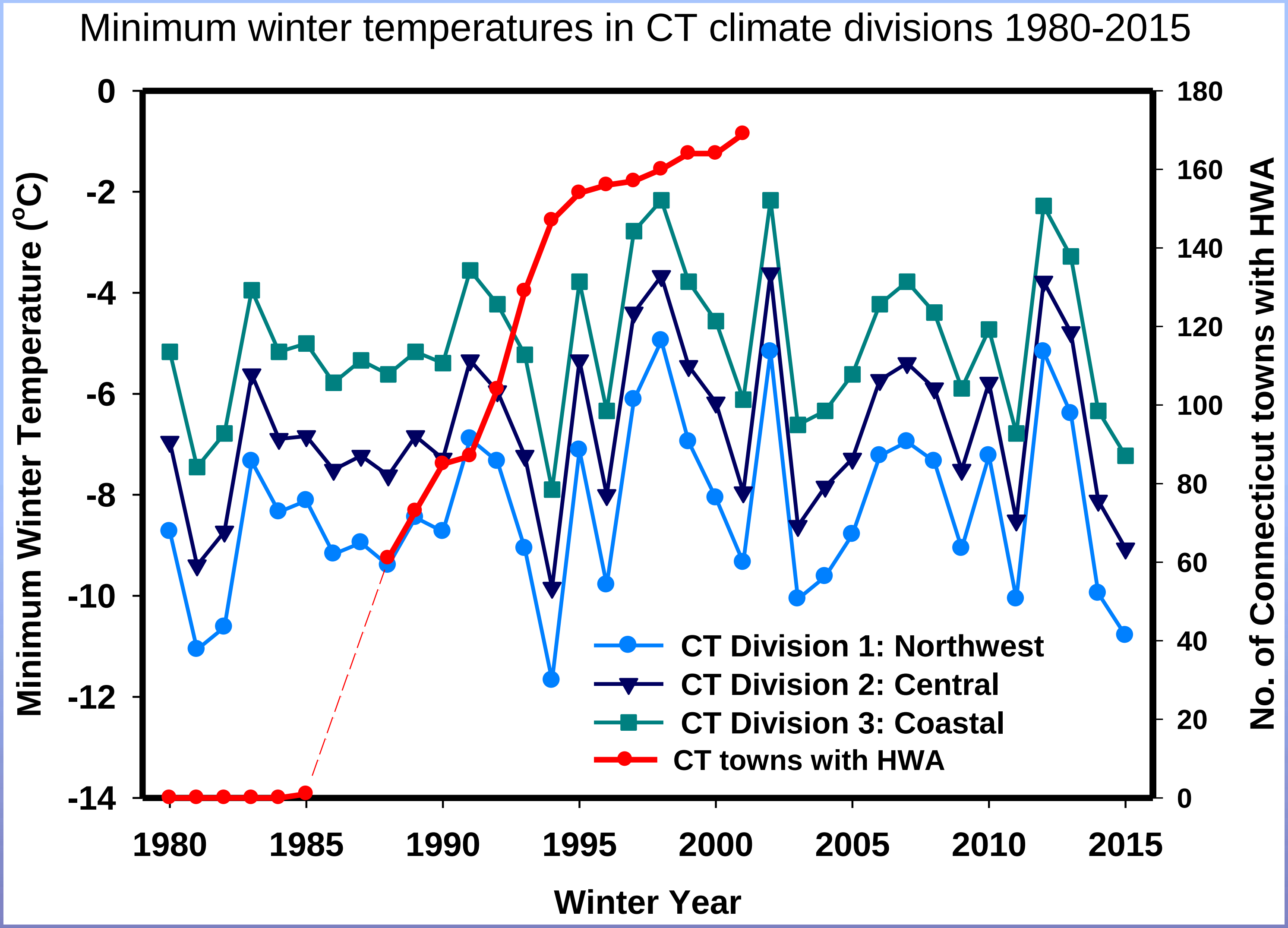






Temperature data from NOAA

Expansion of HWA in Connecticut in relation to winter temperatures



Patterns of Winter Mortality of Hemlock Woolly Adelgid in CT

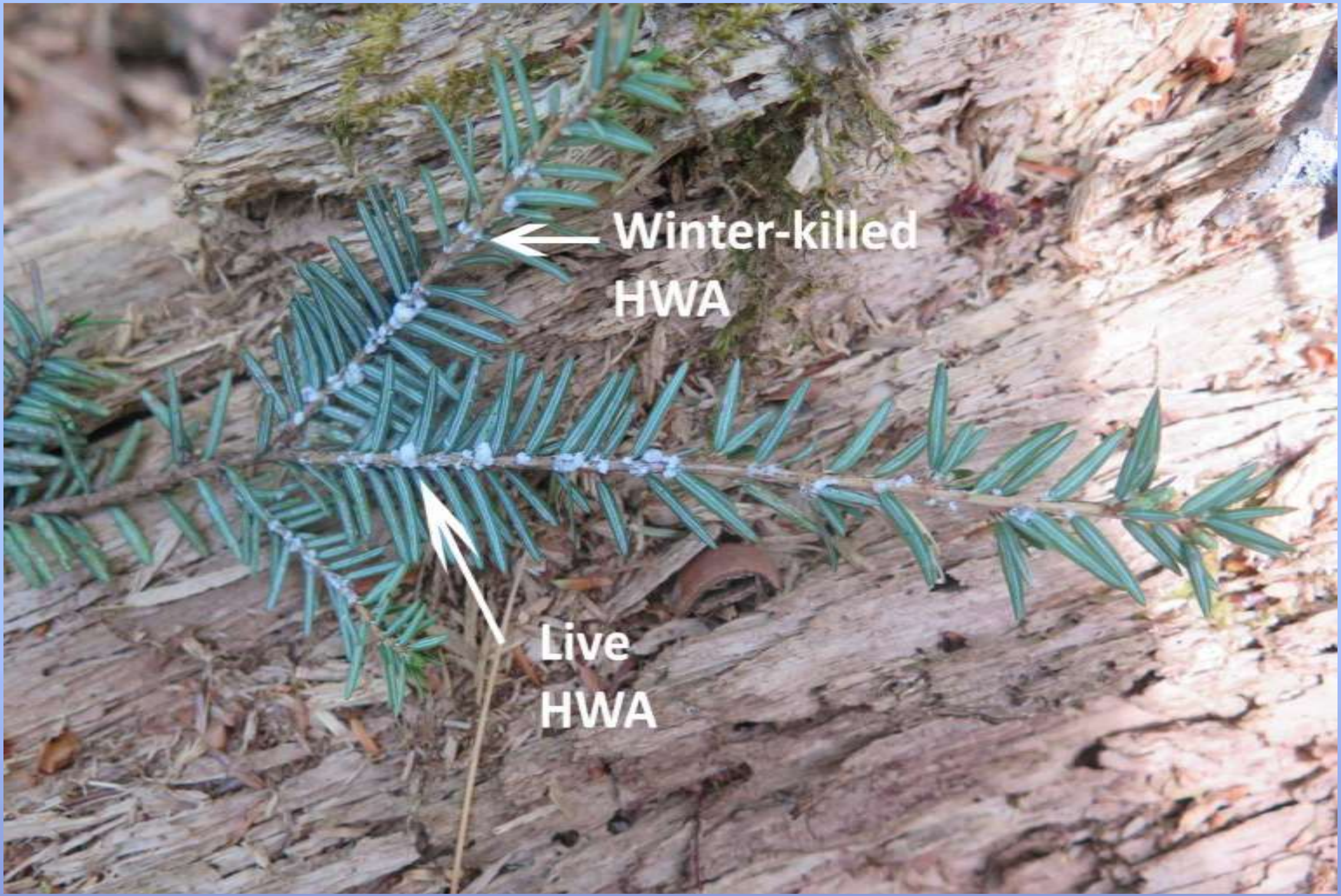
When winters are mild and warm……

When winters are extreme and severe or with a sudden cold snap……..

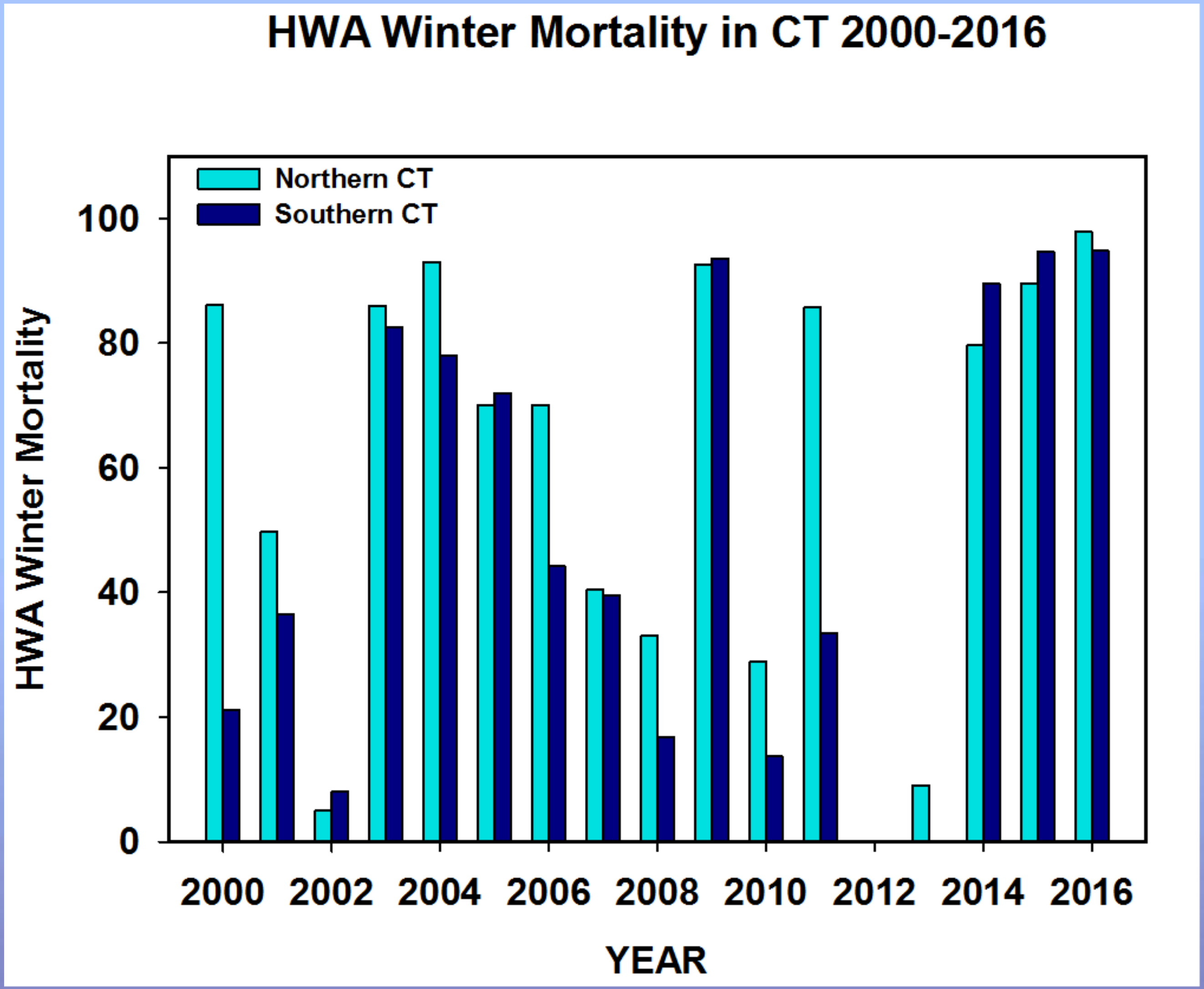
Results from 16 years of data collection

Dead vs Live HWA

Dead HWA are easily detached from stems with a probe and tend to be shrivelled.

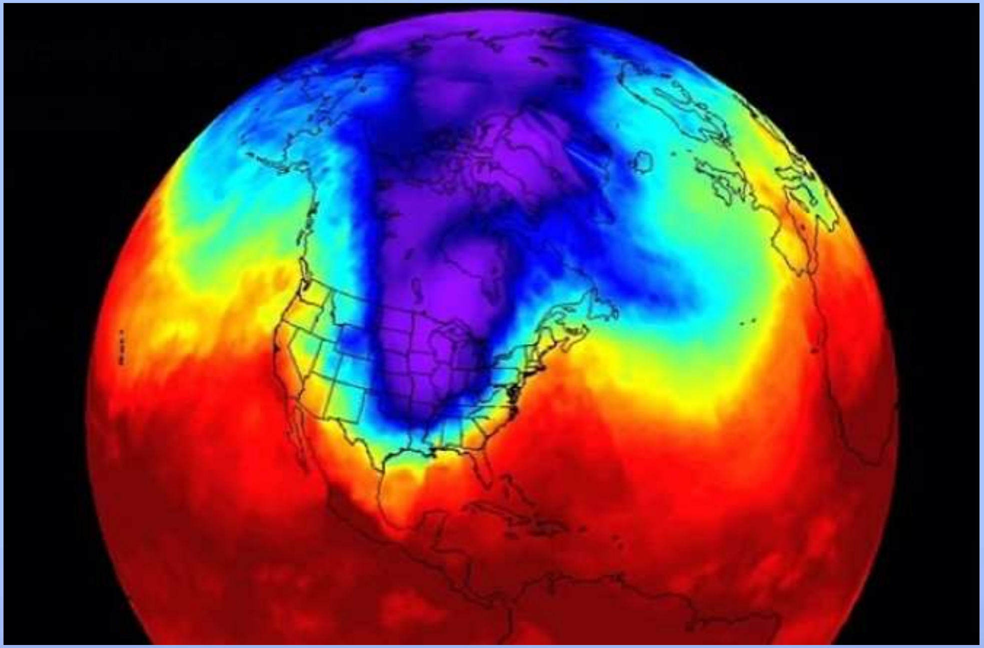

Winter-killed
HWA
Live
HWA

Winter Mortality of HWA in CT 2000-2016



Effects of winter polar vortex outbreaks on HWA survival

What is a polar vortex?



Picture from NASA

Major Polar Vortex Events:
1985, 1994, 1996, 2014, 2015, 2016
2009 was an example of the polar vortex splitting apart

- The polar vortex is a whirling and persistent large area of low pressure, found typically over both North and South poles, flowing west to east (NASA)
- Usually centered over Baffin Island, Canada and NE Siberia, it is strongest in winter
- Occasionally, the polar vortex can either be forced well south of its typical position, or a significant piece of the larger spin can break off and plunge south into the U.S.

(www.wundergrund.com)

Polar Vortex Outbreak

Image from NOAA

2009 Polar Vortex

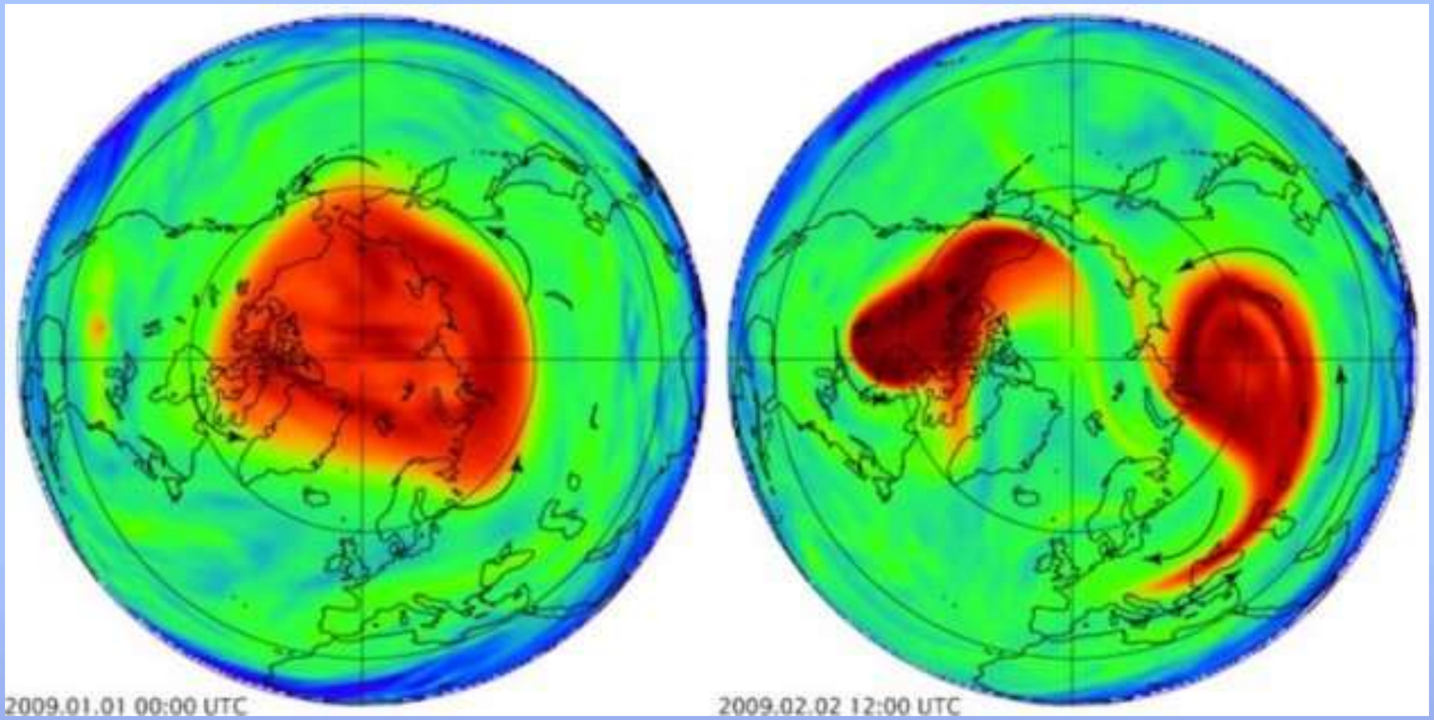
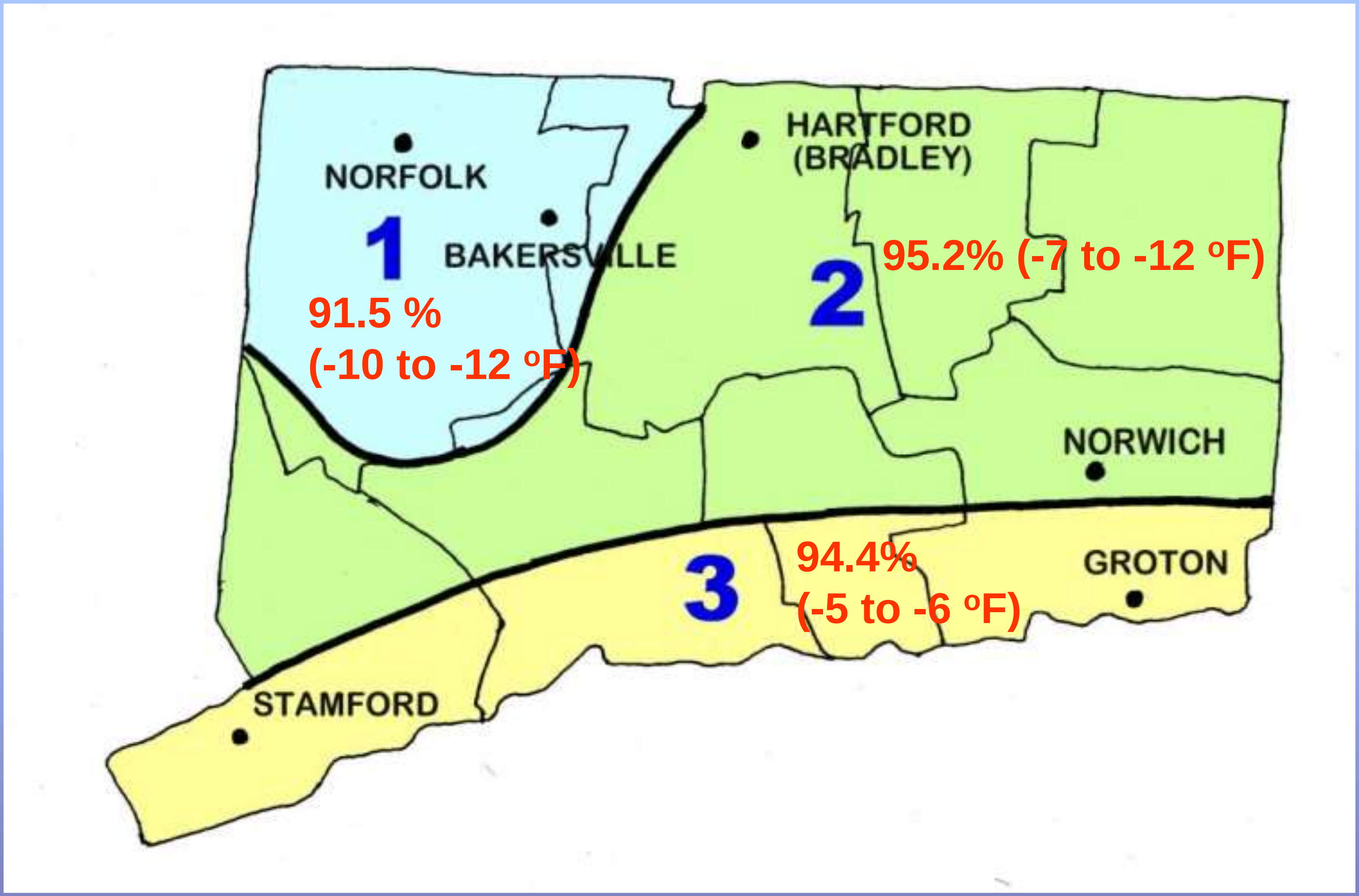
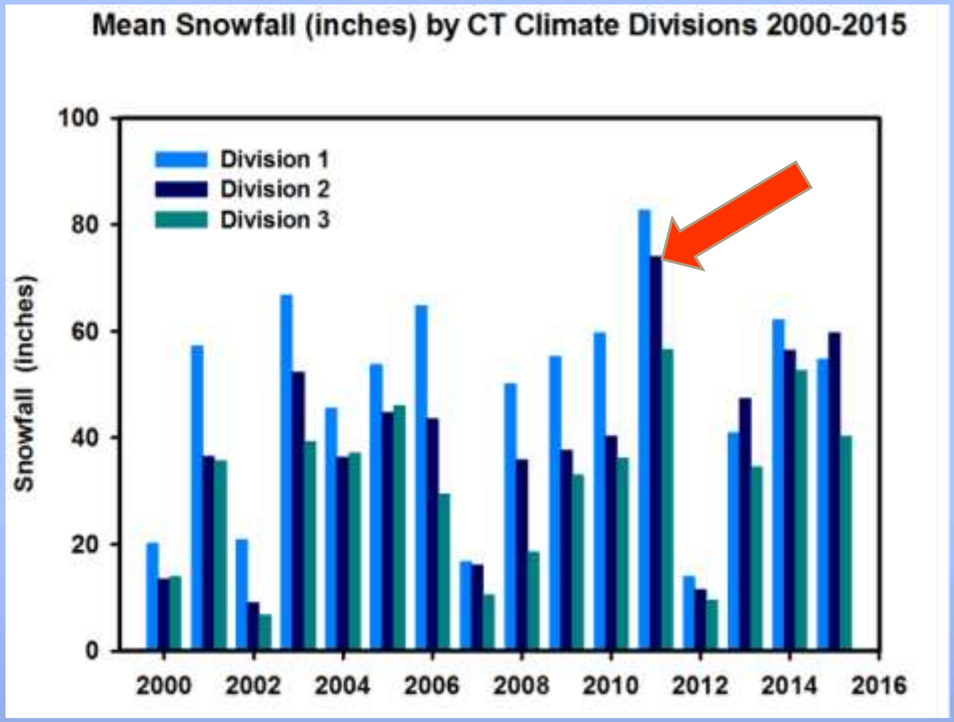


Image Credit: NASA Earth Observatory

The 2009 polar vortex resulted in heavy HWA winter mortality throughout CT

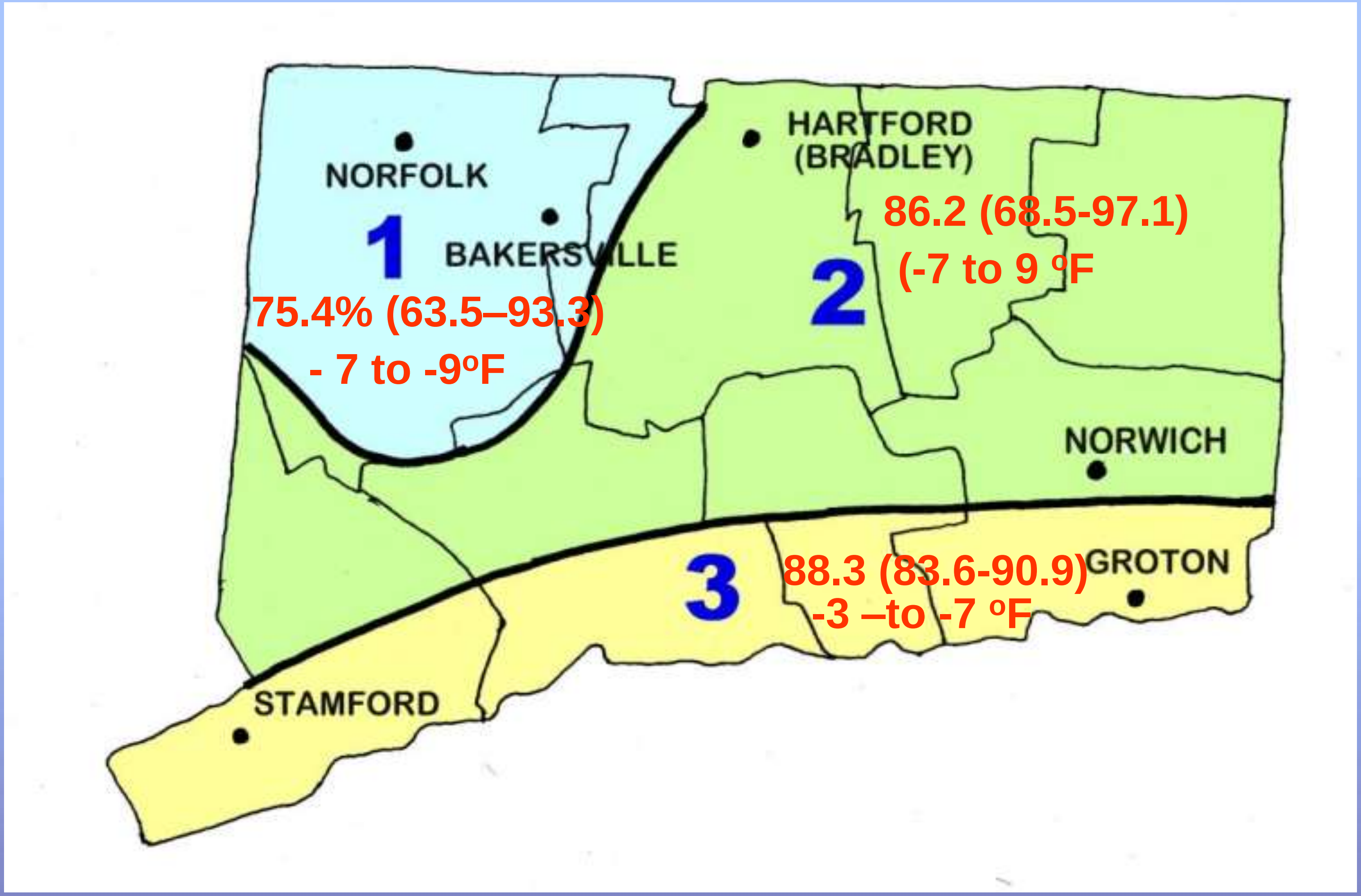


Epic snowstorms in 2011

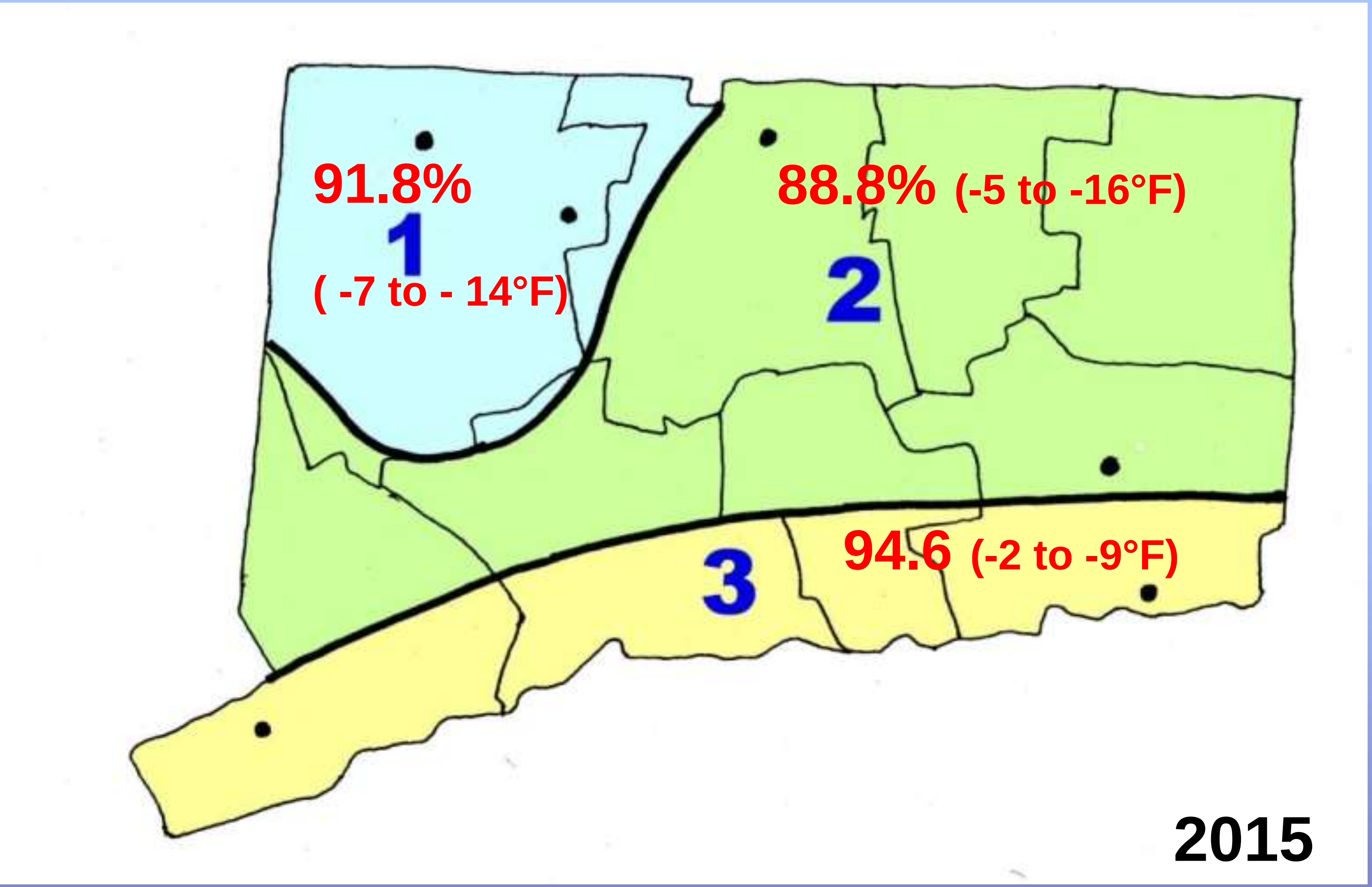


Heavy snow cover can protect HWA and predators from extreme cold

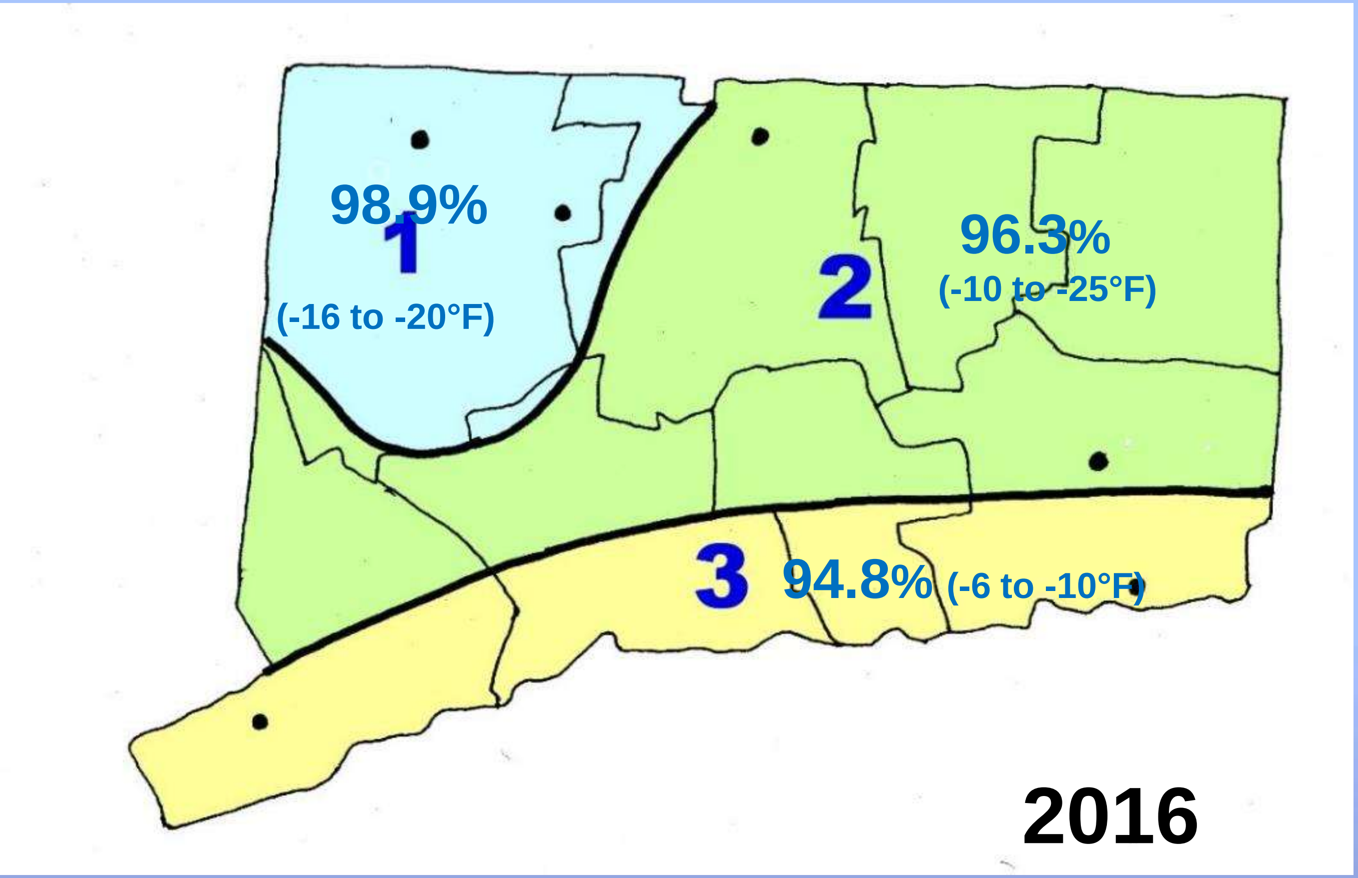
2014 Winter Mortality of HWA



2015 Winter Mortality of HWA

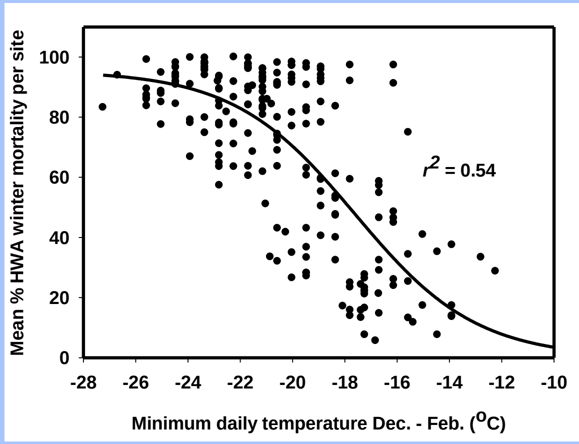


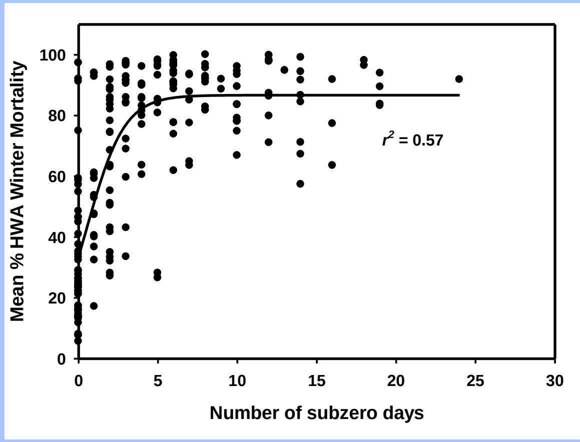
2016 Winter Mortality of HWA

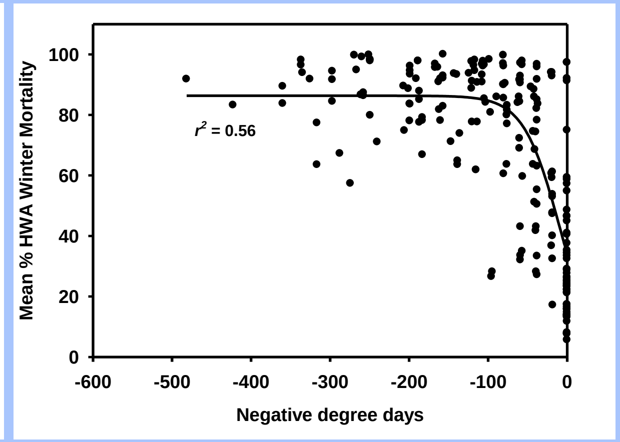


The *greatest* statewide HWA winter mortality (97%) during the *warmest* winter on record….

Important determinants of HWA Winter Mortality





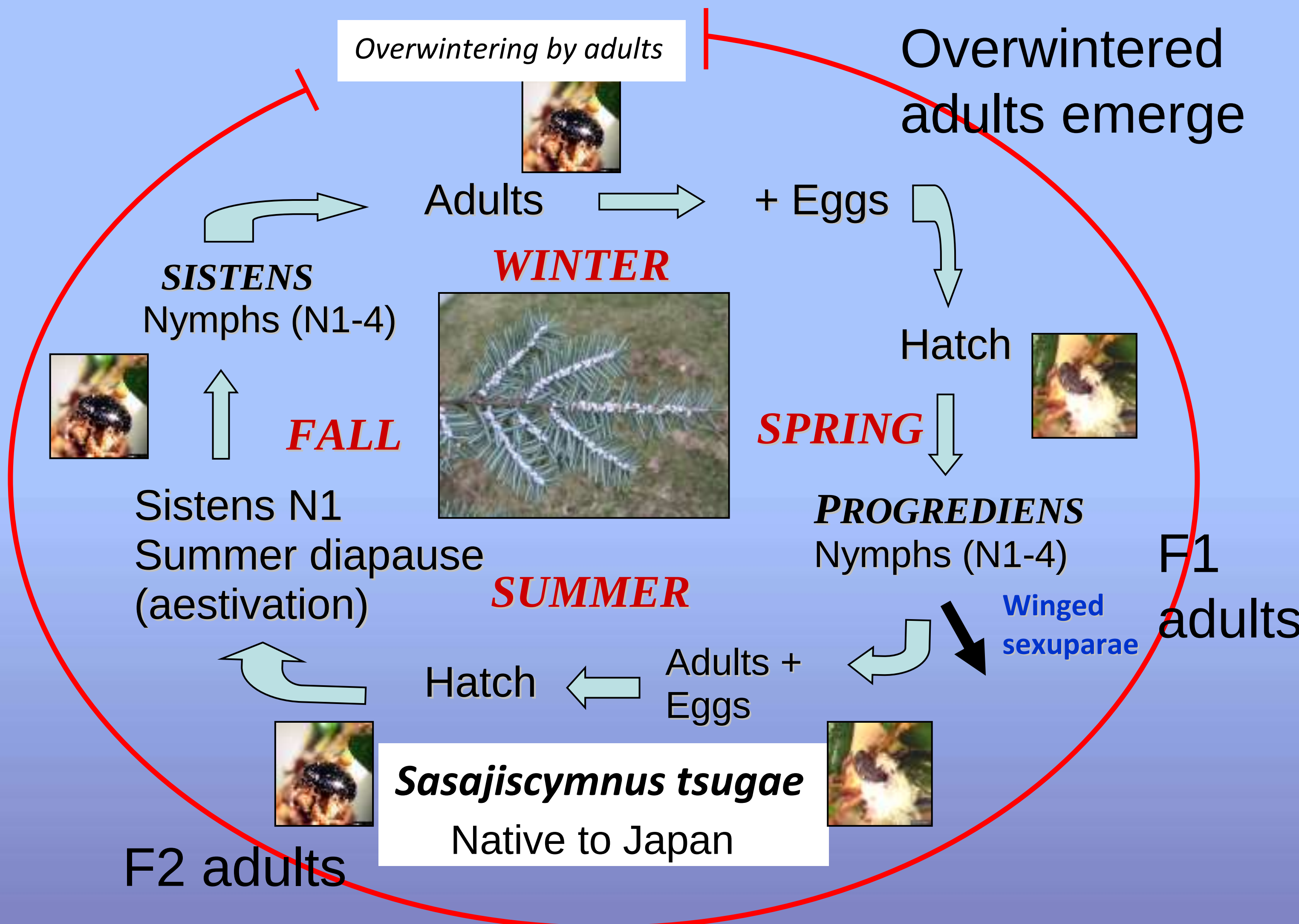


- **Minimum daily winter temperature (December through February) : this is the best predictor**
- **Number of subzero days (Base is 0°F or -17.8°C)**
- **Duration and intensity of subzero cold, expressed as Negative Degree Days or NDD**
- **NDD is a new concept derived from this CT study**

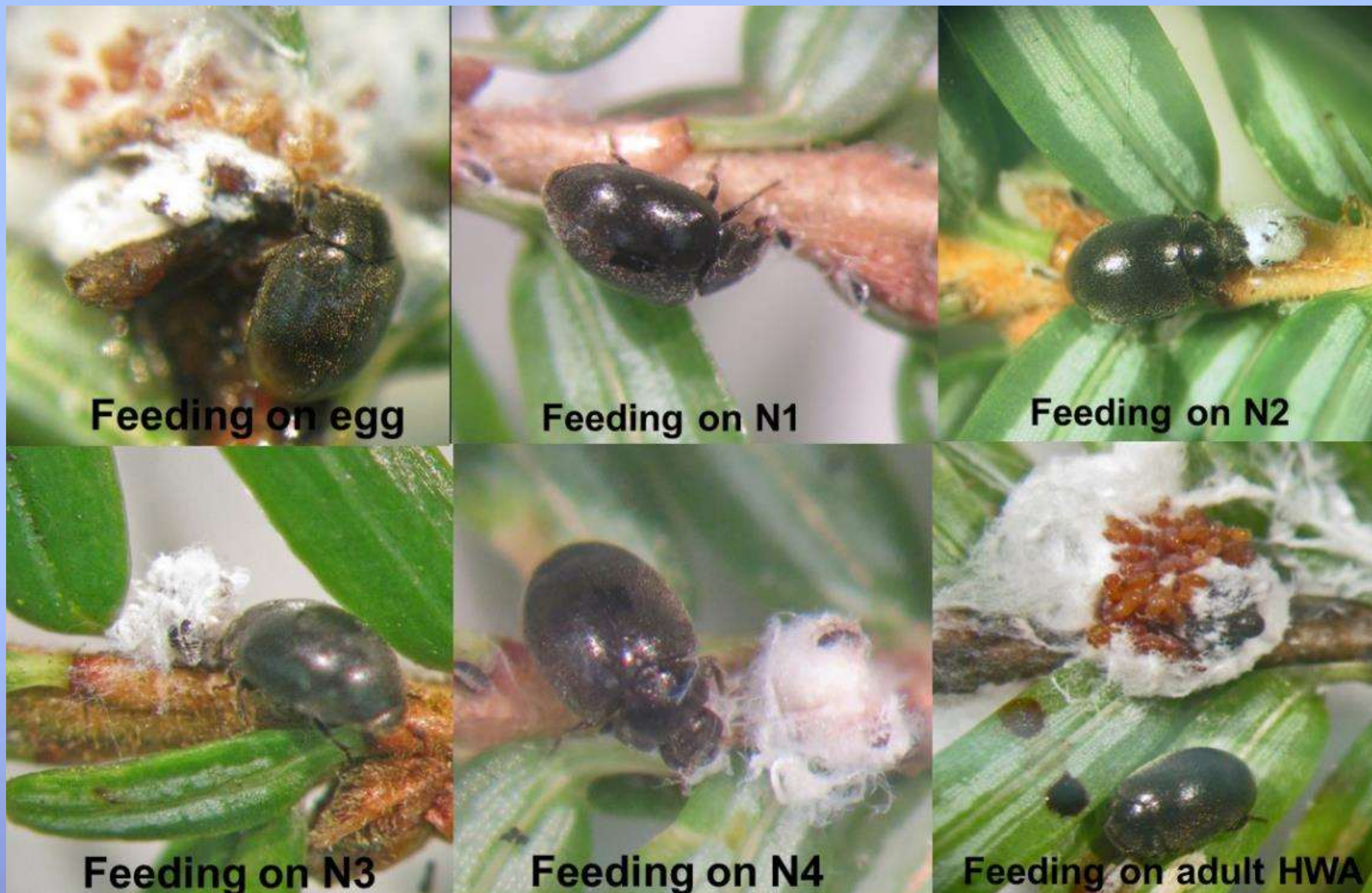
Implications for HWA predators:

current biological control strategies favor winter active predators such as Laricobius spp. reared in field insectaries……..is this practical for the NE?

Life cycle showing active feeding period of *S. tsugae*



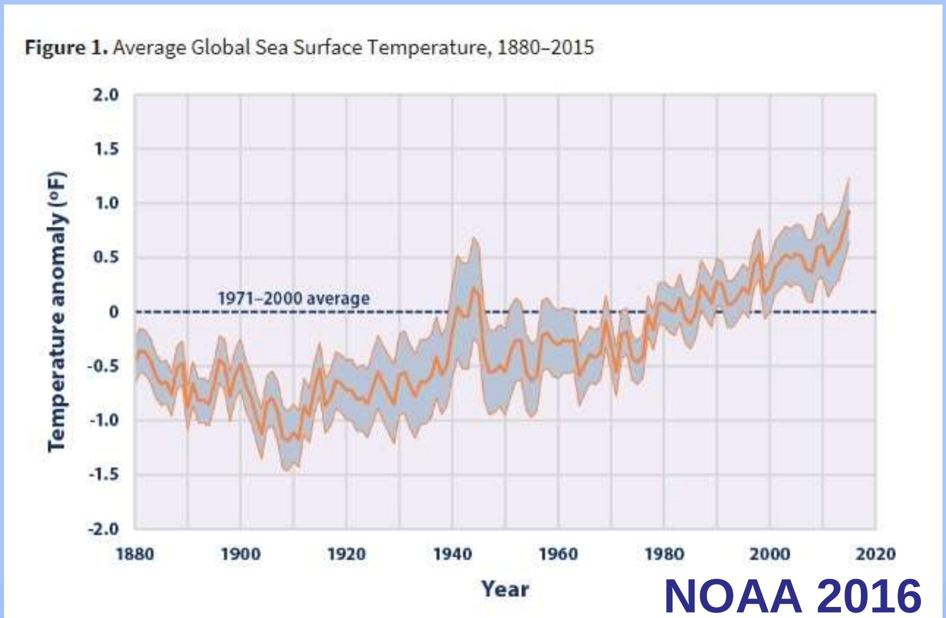
A HWA predator from spring to fall



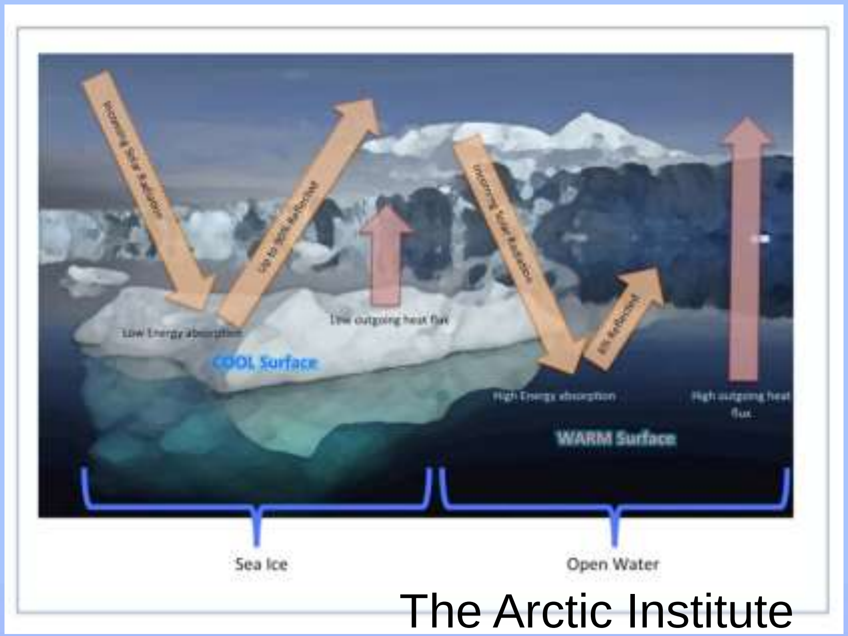
Sasajiscymnus tsugae: the native coccinellid predator from Japan feeds on ALL stages of HWA

S. tsugae larvae eat every stage, too

Average Global Sea Surface Temperatures

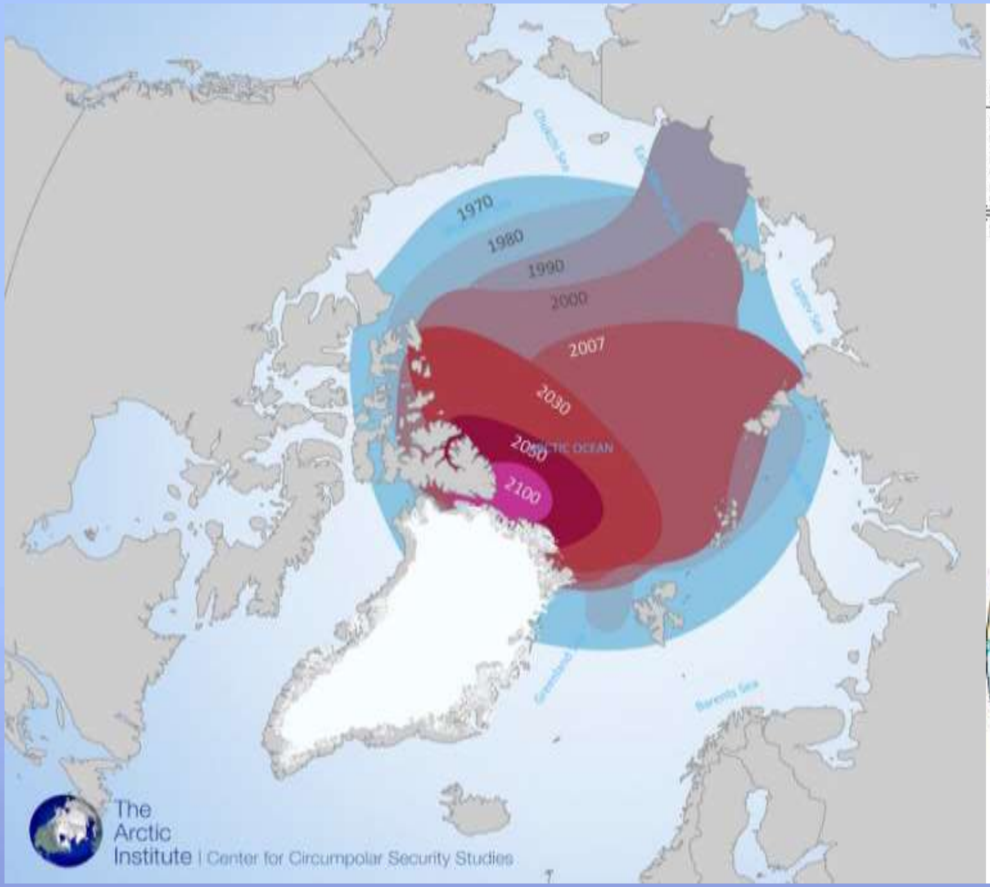


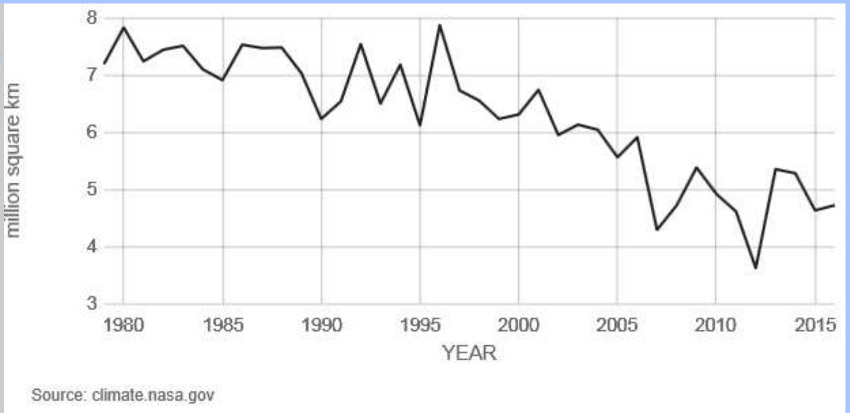
NOAA 2016



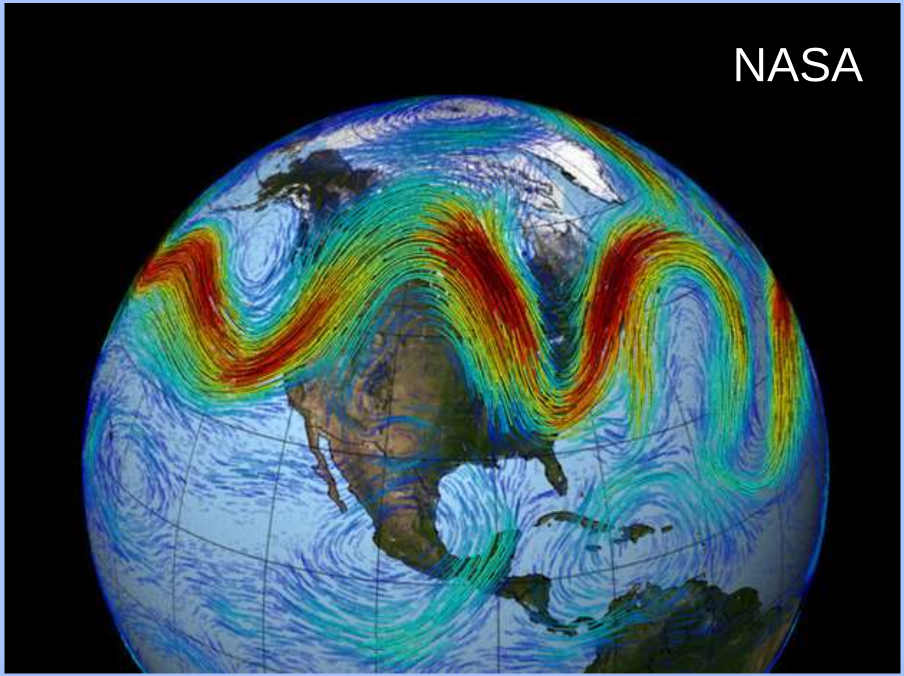
The Arctic Institute

Arctic Sea Ice Minimums





Polar vortex outbreaks may be more of the norm



Recent trends in summer Arctic ice melting, open oceans absorbing more heat, thus warming arctic air, reduces temperature differential between the northern and southern latitudes. Current active research suggests this may cause greater instability of the jet stream, allowing more intrusions of polar air into the lower latitudes.

Range of EHS and HWA (McClure 1991)

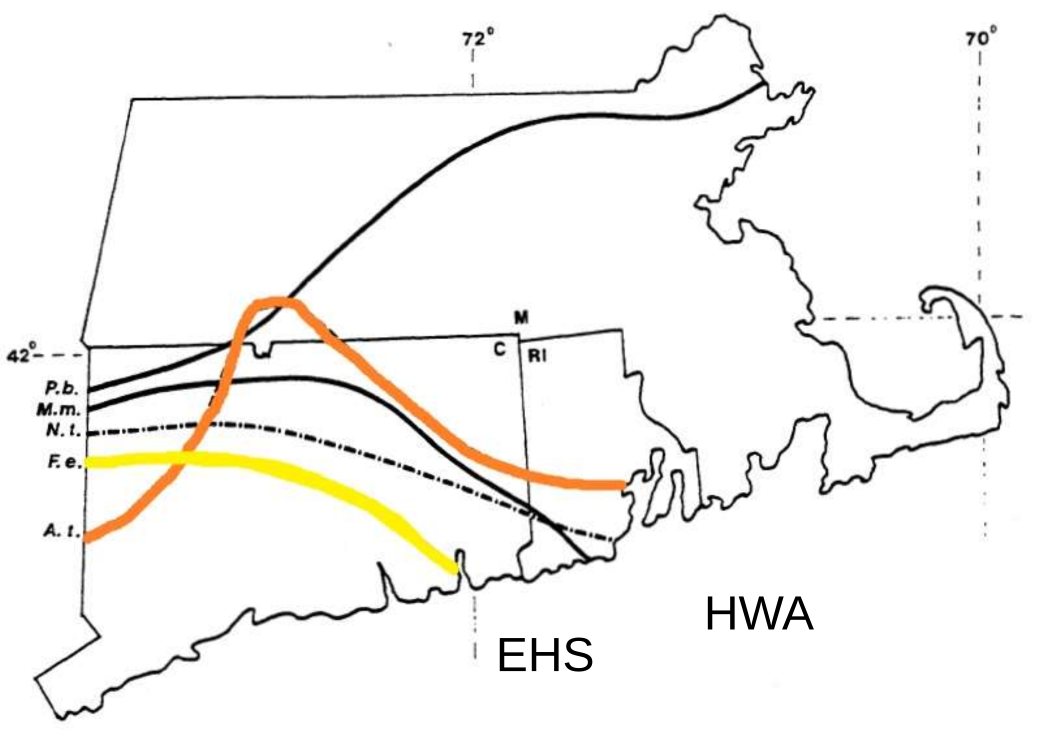
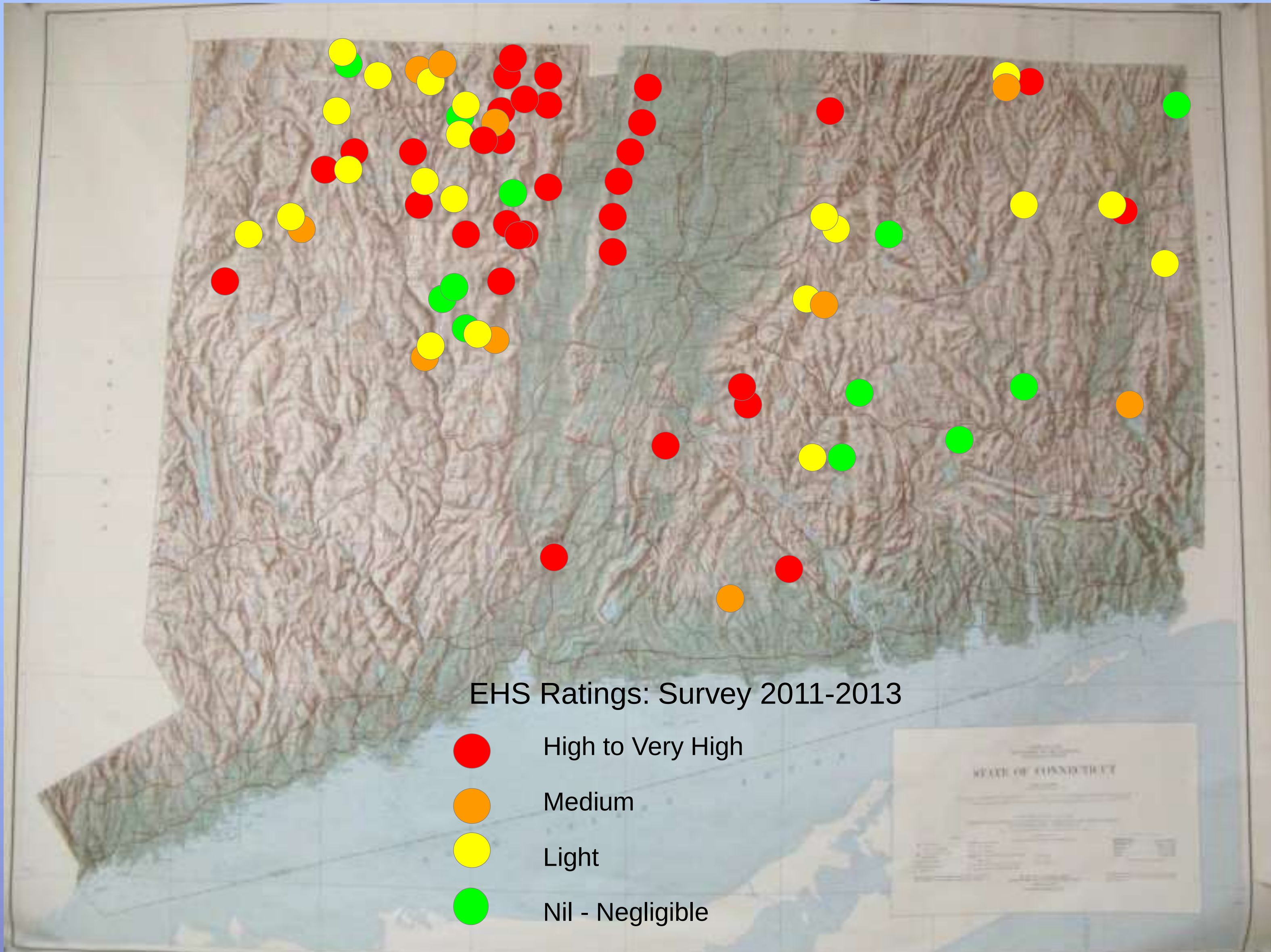
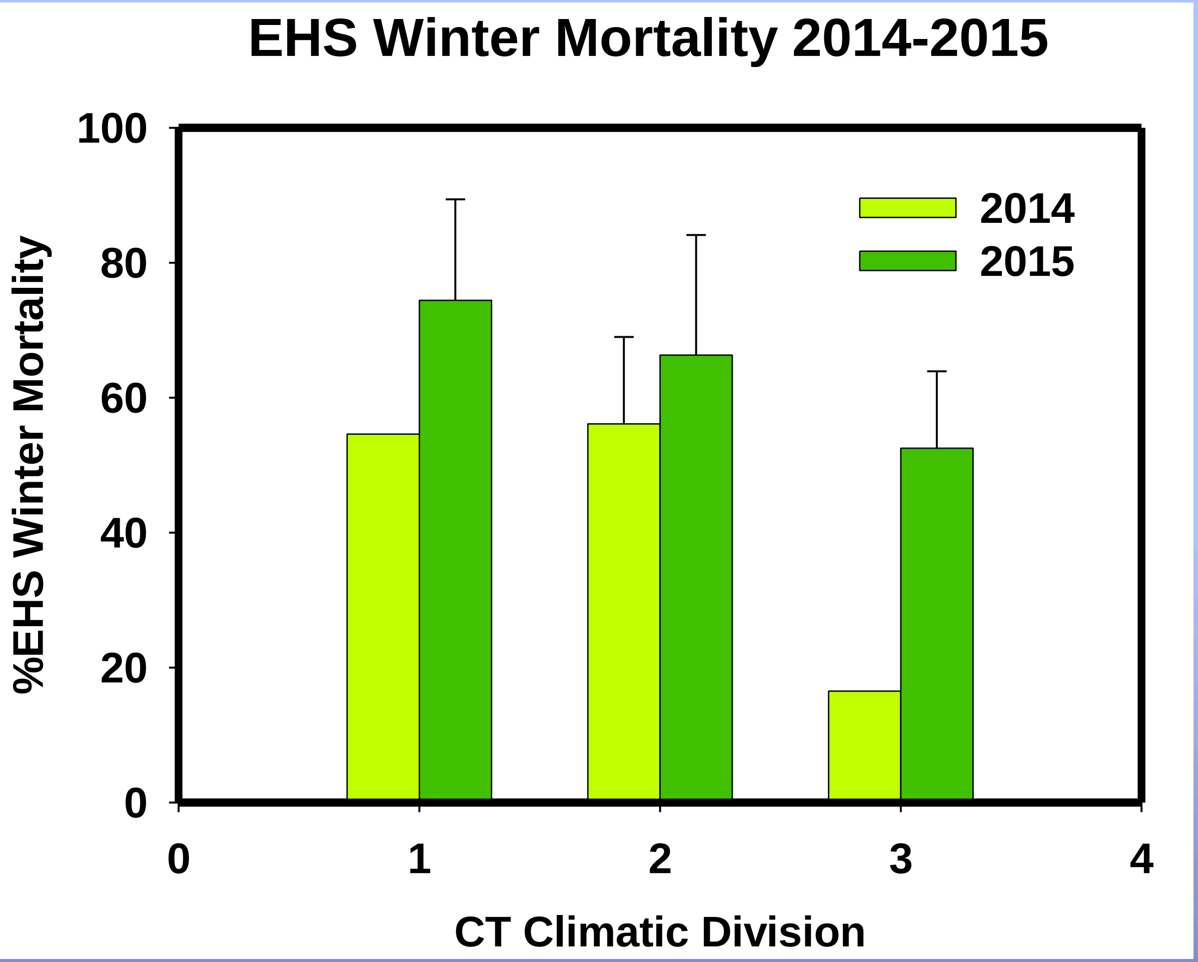


Figure 3. Current distributions (area below each line) of the introduced adelgids and scales on *T. canadensis* and *P. resinosa* in Connecticut (C), Massachusetts (M), and Rhode Island (RI). The species are *A. tsugae* (A.t.), *F. externa* (F.e.), and *N. tsugae* (N.t.) on hemlock, *M. matsumurae* (= *M. resinosae*) (M.m.) and *P. boerneri* (P.b.) on pine.

Connecticut EHS Survey 2011-2013

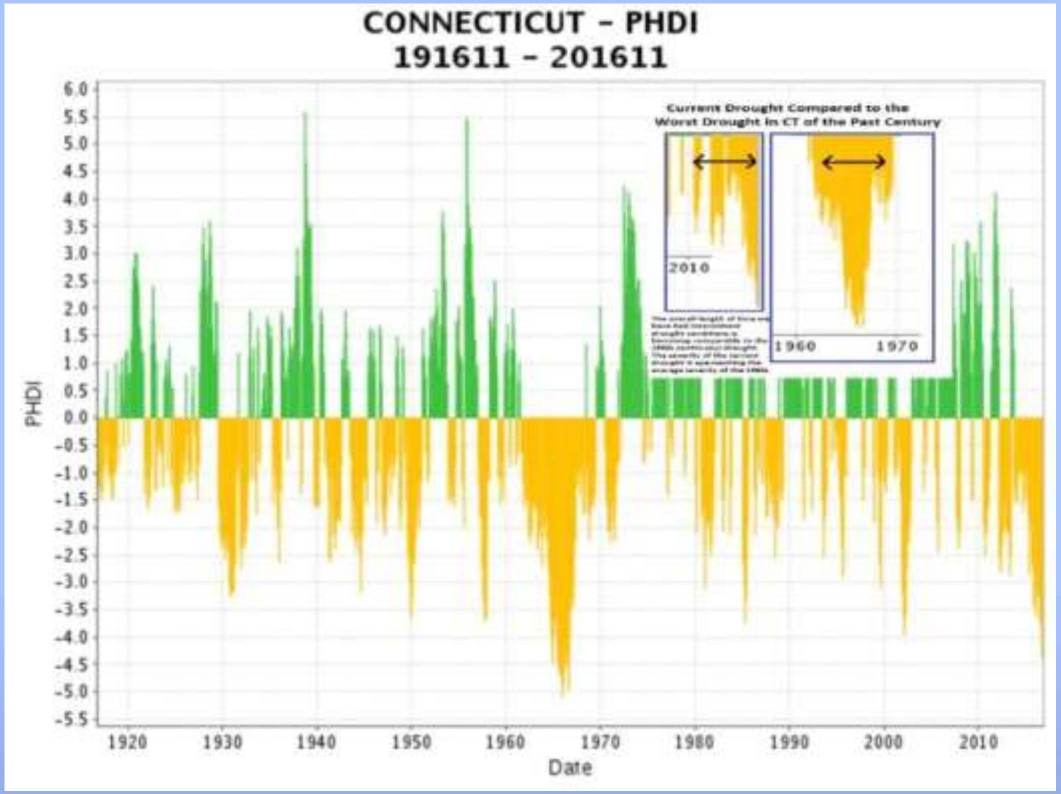


EHS Winter Mortality by CT Climate Divisions



Current drought comparison to historic drought of 1960s

Palmer Hydrologic Drought Index



National Environmental Satellite Data and Information Service, NOAA

http://www.riversalliance.org/drought2.cfm#compare

But hemlocks survived the 1960s historic drought…….

The Impact of Drought + Elongate Hemlock Scale

Upper Barkhamsted Reservoir

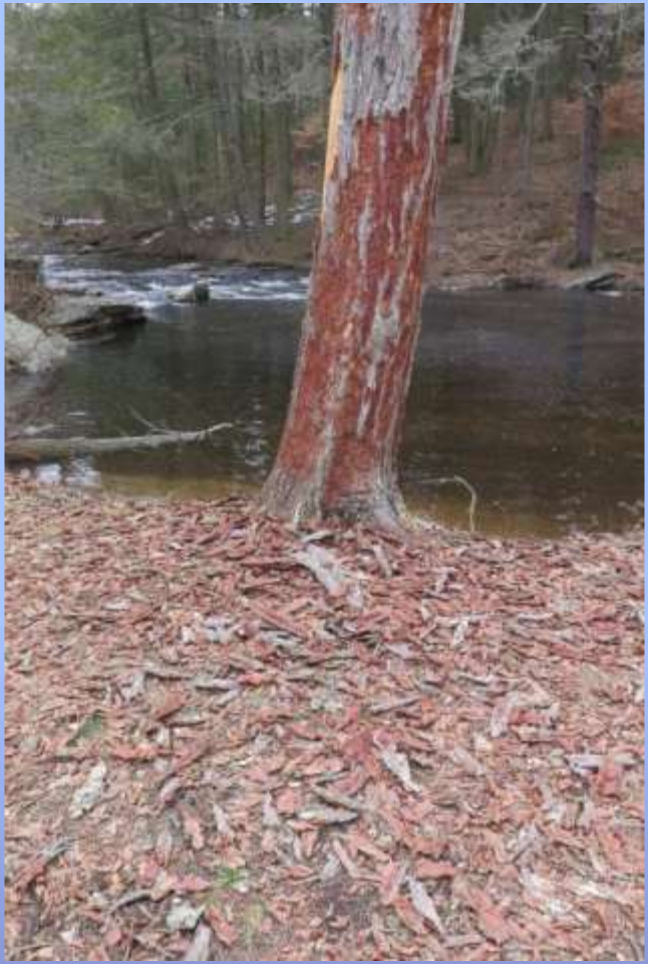
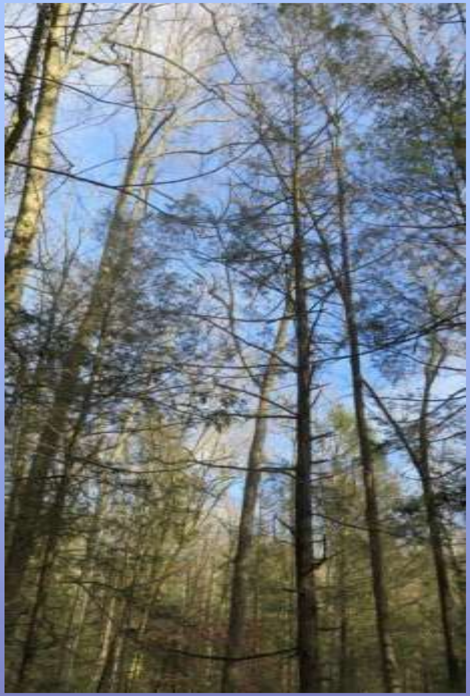
Tunxis SF

Hogback Reservoir 2015

Upper Shepaug River Valley

Extreme Drought + Hemlock Borer in 2016-2017




HWA Summary

- Climate change is influencing the abundance of the invasives; impact on predators?
- In spite of the trend in warming winters, back to back polar vortex incursions have reduced HWA in the forest and landscape to their lowest levels since 1985
- Extreme, prolonged drought coupled with previous EHS buildup now threatening hemlock survival, especially on marginal sites; major outbreaks of hemlock borer may be imminent.
- Predators like *Sasajiscymnus tsugae,* which target resurgent spring and summer HWA should be released after extreme winters to maintain HWA at low levels in the forest. *S. tsugae* is available commercially!

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Biological Control of MAM in CT

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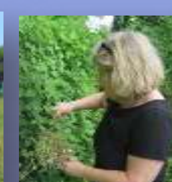


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MAM Biological Control

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2009-2012