Climate Impacts on Eastern Hemlock Sustainability

By Carole Cheah

Eastern or Canadian Hemlock, *Tsuga canadensis* (L.) Carriere, is the second most common native conifer in Connecticut, with an extensive range in eastern North America. Though not considered a valuable timber species, hemlocks play a vital and important ecological role in our forests and wetlands. Hemlocks occur from eastern Canada and Maine down through the mid-Atlantic Appalachian Mountains to its southernmost limits in northern Alabama, and westwards through Ohio, Michigan and Wisconsin to its northwestern fringe in eastern Minnesota. Our Connecticut hemlock resources are concentrated in the northwest corner, but large stands of hemlock also occur in the northeast and southeast. Hemlocks are shallow-rooted species which require moist, cool conditions and grow well where there is 29 - 50 inches of precipitation. In its northernmost distribution, hemlocks can grow in pure or mixed stands at sea level, but hemlock sites gradually increase in elevation to 5,000 ft in its southern range and are more restricted to north or east facing cooler slopes or deep valleys. Natural hemlock sites can be quite varied as hemlocks can grow on different soil types and are abundant on mesophytic sites but can also be found on more xerophytic slopes. They are also dominant in saturated hemlock swamps *(Figure 1)* in acidic forested wetlands. Being the most shade-tolerant species which can live for several hundred years, eastern hemlock is considered by ecologists as a foundation species. Communities of animals and plants have uniquely adapted to the structure, microclimate and ecological processes of the eastern hemlock ecosystem. The towering evergreen crowns of hemlocks cast deep shade which are critical for the thermoregulation of cold, clean stream waters for native brook trout and rare salamanders. In Connecticut, the northern spring salamander, a threatened species, requires steep rocky hemlock habitat. Many other species of wildlife call hemlock groves and swamps home, from obligate birds such as certain warblers and thrushes which are strongly associated with hemlock forests for breeding, to ruffed grouse, red squirrel, northern flying squirrel, porcupine, deer, black bear, bobcat, and many more that rely on eastern hemlocks for cover, forage and habitat.

Our climate is undeniably warming, with serious implications to the health, diversity and sustainability of tree species and forest ecosystems in the Northeast and beyond. Abiotic stressors such as drought and excessive heat alone, for example, have severe impacts on tree health. Connecticut has recently experienced the second most extreme and prolonged drought from 2016 to 2017 since the epic exceptional/extreme drought of the mid-1960s, which lasted from 24-27 months in the three climate divisions of Connecticut (data from the Northeast Regional Climate Center). In 2016-2017, Connecticut streams ran dry, well and reservoir levels were severely reduced in some areas. This recent extreme drought lasted 11 months in northwest Connecticut (Division 1), 13 months in Central Connecticut (Division 2) and a staggering 22 months in coastal Connecticut (Division 3). Abnormally dry conditions were actually in effect for even longer and the resulting stress on trees was significant. Concurrently, 2016 was the second hottest year in Connecticut since 1895. Such extreme drought and heat were detrimental to hemlocks and other species. For shallow-rooted hemlocks, drought can be the silent and overlooked major abiotic cause of tree decline and death, creating the conditions that allowed outbreaks of the native hemlock borer,

Figure 1. A hemlock swamp in New Hartford, Connecticut. Photo by Carole Cheah.

hemlock, continued on page 7

hemlock, continued from page 6

Phaenops (formerly *Melanophila*) *fulvoguttata* Harris to overwhelm and kill trees already weakened and stressed by non-native major insect pests such as the elongate hemlock scale, *Fiorinia externa* Ferris or EHS *(Figure 2)* or the more widely-blamed hemlock woolly adelgid, *Adelges tsugae* Annand or HWA *(Figure 3)*, which are both native to Japan. In 2016 and 2017, several hemlock borer outbreaks in Connecticut were observed on some ridgetop sites with the thinnest soils where drought effects were extreme, resulting in heavy decline, needle loss and tree mortality.

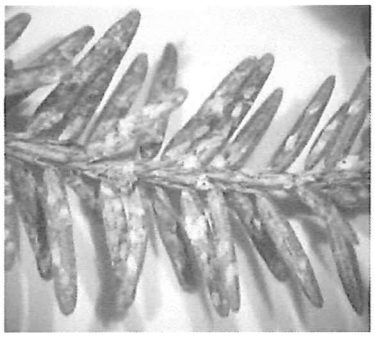

Figure 2. Elongate hemlock scale. Photo by C. Cheah

Prior to the accidental introduction of exotic hemlock pests, the greatest insect threats to hemlocks were native and infrequent: the hemlock borer and a native defoliator, the hemlock looper, *Lambdina fiscelleria fiscellaria* Guenèe. In Connecticut, the exotic EHS, an armored scale which feeds on the needles of many conifer species, actually preceded HWA, arriving in Connecticut in the 1970s, then spreading quickly in Fairfield County to kill weakened hemlock survivors of the historic 1960s drought. The scale generally has one generation in the Northeast and mostly overwinters as female adults or eggs and the lack of effective natural enemies has allowed the slow spread of EHS infestations east of the Connecticut River in the last decade. Hemlocks in Connecticut, especially west of the Connecticut River, have been attacked by both EHS and HWA for many years. Needles become chlorotic from heavy EHS feeding and premature hemlock needle drop weaken and kill trees, often

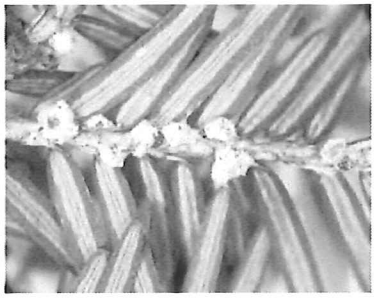

Figure 3. Hemlock woolly adelgid Photo by C.Cheah

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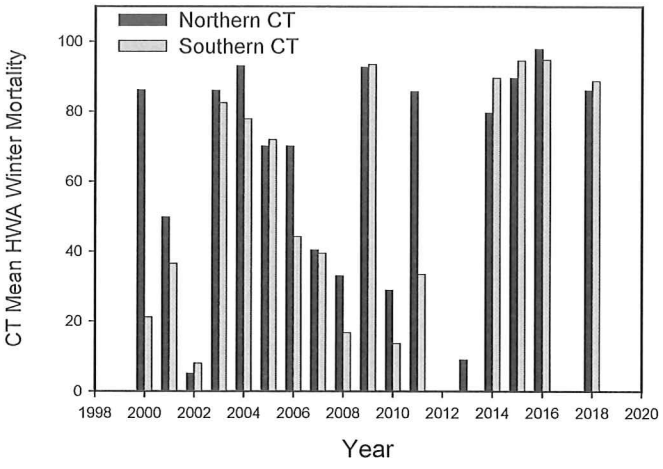
exacerbated by concurrent drought. Tree decline and mortality resulting from EHS and/or hemlock borer attacks, and drought are often misdiagnosed and attributed to HWA without careful tree inspection of the true primary casual agents.

Native eastern and Carolina hemlocks, *Tsuga caroliniana* Engelmann, are susceptible to HWA attack and damage. Hemlock woolly adelgid was first reported to the Connecticut Agricultural Experiment Station in New Haven in 1985 and quickly spread to all 169 Connecticut towns by the late 1990s during a period of warming winters. Severe drought was also recorded in 1995 and 1999 in coastal division 3 and peak damage from HWA was observed in the Connecticut River Valley and near the shoreline. All HWA are females and there are two generations which facilitate rapid population explosions on healthy hemlocks. The sistens or winter HWA generation consists of nymphs which break dormancy in the fall to feed and develop through the winter, becoming adults which lay many eggs in early spring. These hatch into nymphs which develop as the shorter progrediens generation in late spring and early summer, and generation size is dependent on the survivors of the winter generation. Adelgids do best on the newest most nutritious hemlock growth and feed along the stem on storage cells. At high densities, HWA feeding damage results in needle loss, lack of new growth and tip dieback. Hemlock woolly adelgid populations also subsequently crash due to a negative density-dependent feedback loop. Unchecked populations of HWA can build up to cause severe hemlock decline and even tree mortality, particularly under other stressful environmental conditions.

Over 18 years of research in Connecticut has shown that while warmer winters result in high survival of HWA, cold winters, particularly in the Northeast, can periodically reduce HWA sistens populations, which are actively feeding in winter. In Connecticut, there has been severe winter kill of HWA (80-97% statewide) in the consecutive winters of 2014, 2015, 2016 and 2018 *(Figure 4)*, resulting in the historic current decimation of HWA populations on Connecticut hemlocks throughout the state. Data from Connecticut is contrary to current hypotheses and projections of continued HWA range expansion and hemlock extinction with climate change and warmer winters.

Figure 4. Mean winter mortality of HWA in northern and southern Connecticut from 2000-2018. (C. Cheah 2018)



Conventional predictions of global warming and milder winters with northward expansion of invasive species present an apparent paradox to these findings, except this is really not a contradiction at all. A deeper understanding of changing climate processes and the specific biology of HWA and its host reveals clues to a more hopeful future perpetuation of eastern hemlocks. Recent and ongoing climate research point to a rapidly warming Arctic as one of the primary drivers of the recent weak polar vortex events that have resulted in winter incursions of bitter Arctic cold into the lower latitudes. As the Arctic is warming at more than twice the rate of the rest of the Earth, apparent in the ever decreasing Arctic sea ice cover each winter, this destabilizes the jet stream, which forms the boundary between the cold polar vortex of Arctic winds and the warmer winds to the south. A wavy jet stream brings more arctic air south in unpredictable magnitudes which can kill high percentages of HWA. Connecticut research continues to document how frequently these arctic air incursions are impacting HWA winter after winter *(Figure 4)*.

Recent analyses of patterns of HWA winter mortality in Connecticut indicates the close relationship to weak polar vortex events and how cold adaptation of HWA is related to climate divisions in Connecticut. Populations of HWA in the coastal division appear to be less cold-hardy than HWA in northwest and central divisions. Analyses showed that the absolute minimum daily winter temperature was the best predictor for the extent of HWA mortality in the different climate divisions. Adelgid mortality could also be predicted by the number of subzero days (below 0 °F) and cumulative subzero cold

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hemlock, continued from page 13
called negative day degrees during a meteorological winter. Connecticut predictions were validated in the winter of 2016, which was the warmest winter for the state since 1895, and yet resulted in the highest ever recorded HWA winter mortality for the state at 97% since the start of data collection in 2000. An extreme cold outbreak from a split polar vortex which lasted only a few hours before dawn on February 14, 2016 plunged the state to minimums we have not experienced in decades. This brief but extreme cold from -20 °F to -25 °F in interior Connecticut to -10 °F along the coast was sufficient to kill 95-99% of HWA statewide. However, snow cover is also protective of HWA leading to higher winter survival. But there are management tools such as biological control of HWA that can be implemented to target any HWA resurgence in the forest. Releases of the HWA predatory ladybeetle, *Sasajiscymnus* (formerly *Pseudoscymnus*) *tsugae*, native to Japan, have been the major strategy in Connecticut where >178,000 have been released throughout the state since 1995. This species is also the only one reared commercially and available to the public through a company in Pennsylvania (https://tree-savers.com/).

So the tables have turned and hemlocks are now experiencing an extended reprieve from HWA, although EHS remains a challenge and continues to impact hemlock health on stressed sites as the latter are not as susceptible to winter extremes. Another surprising outcome of our changing and unpredictable climate has been the effects of the heavy precipitation that ended the recent extended drought. I am currently documenting the rapid recovery and resilience of hemlocks in previous decline in response to the return of heavy rains in 2017 and the above normal precipitation of 2018. For eastern hemlocks, more frequent polar vortex fueled arctic outbreaks and increased precipitation in a changing climate may yet prove to be critical to the future sustainability of eastern hemlock in the Northeast.

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