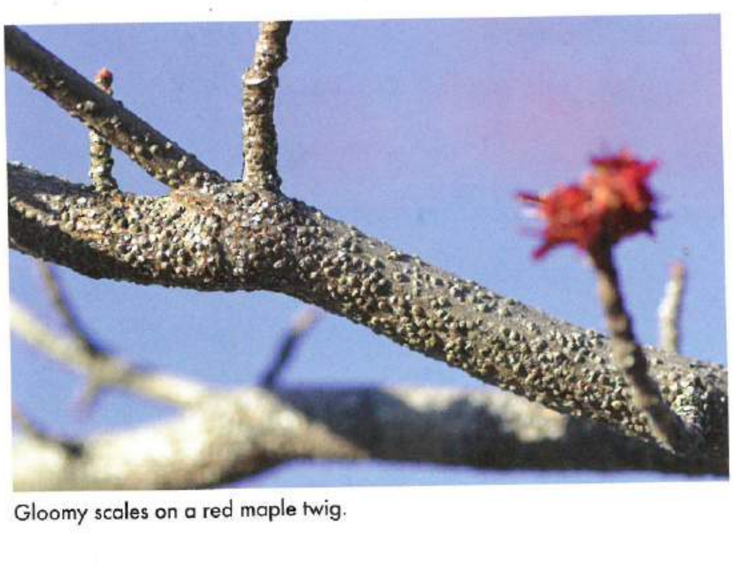
The Vicious Cycle of Stress

By Steven D. Frank

Urban and forest trees have to deal with stress from drought, pests, and increasingly high temperatures. Of course, trees have faced these challenges for millions of years, so forest trees are generally resilient to occasional bouts of stress. Urban trees have a tougher time. Urban trees may be subject to drought, pests, and high temperatures all at the same time and frequently, or even continuously, rather than occasionally. Understanding how high temperatures and drought create a vicious cycle of stress that increases tree pests and reduces tree health has been a primary goal of research in my lab. The more we learn about these stressors, the more we can plant and manage trees to avoid them.

Urban trees often have more arthropod pests and damage than rural trees. In cities it is common to find trees covered in galls or scale insects or caterpillars, but take a walk in the woods and these instances are rare. Our hypothesis has been that impervious surfaces, which increase temperatures and reduce soil moisture, are primary causes of scale insect infestations. We have studied red maples (*Acer rubrum*) and willow oaks (*Quercus phellos*) for several years to understand the relative influences of heat and drought on pest susceptibility and tree growth. We study these trees because they are two of the most commonly planted urban trees and because they are frequently infested with scale insects.

Red maples frequently have an armored scale called gloomy scale (*Melanaspis tenebricosa*). Gloomy scales are native to the United States and are most common in the southeast, although they seem to be spreading north as the climate warms (but that's another story). They have one generation per year. They live on the bark of tree trunks and branches feeding on fluid from parenchyma cells. The most common scale insects on willow oaks are oak lecanium scales (*Parthenolecanium quercifex*), a native soft scale present throughout eastern North America. Lecanium scales feed on phloem in twigs and leaves and also have one generation per year. Infestations of gloomy scale, lecanium scale, and many other scales can initially cause small twigs to die and reduce twig growth, making tree canopies thinner. At high densities, scales can cause branch dieback and reduce overall growth and condition.



Gloomy scales on a red maple twig.

To start this research, we studied scales on established red maples and willow oaks growing in hotter and cooler sites within the Raleigh, North Carolina, U.S., urban heat island. Although cities are hotter than rural areas—a phenomenon known as the urban heat island effect—cities are mosaics of thermal patches that can range from close to rural temperatures to several, even 10°C (18°F), above rural temperatures. We counted scales on red maples and willow oaks around Raleigh and found that at hotter sites scale insect density increased drastically. Gloomy scale density increased 200 fold on red maples, as tree canopy temperature increased just 2.5°C (4.5°F), while lecanium scales increased 12 fold on willow oaks across the same temperature range. On both species this meant a lot of scales. The hottest red maples had over 300 scales per inch!

Tree temperature increased as the amount of impervious surface cover around a tree increased. Since impervious surface cover reduces water penetration and soil moisture, our hottest trees were also the most drought-stressed. To unravel the mechanism of why scales became more abundant on red maples surrounded by lots of impervious surface, we started watering.

We found 24 sites in Raleigh that ranged from almost no impervious surface cover to almost 100% impervious surface cover. At each site we selected a pair of red maples. One tree in each pair was fitted with watering bags that delivered 80 gallons (302.8 L) of water per week from May to August for two years. With this approach, we could study scales across a range of temperatures on trees that were drought-stressed and trees that weren't. To identify a mechanism for why scales become so abundant on hot trees, we compared scale reproduction. To do this, we measured female scales and counted the embryos (eggs that hadn't been laid) within them. This is not as easy as it sounds, but the results were worth it. After measuring and dissecting thousands of scales, we found that scales on the hottest, unwatered trees were 20% bigger than scales on cool, watered trees. More importantly, scales from hot and dry trees had around 50 embryos, whereas cooler unwatered trees had around 40. This confirmed that heat alone increases scale reproduction. However, cooler watered trees produced just around 30 embryos, confirming that both heat and drought stress increase scale reproduction, which contributes to the high gloomy scale densities on many urban red maples.

Since oak lecanium scales became more abundant on the hottest willow oaks in Raleigh, we wondered if drought was also a factor in promoting these soft scales and ultimately how all three stresses (i.e., heat, drought, and pests) combined to affect tree growth. After all, if trees have lots of pests but keep growing, it is much less of a problem than if they don't.

So we started with an experiment in growth chambers as big as bedrooms in which we could manipulate temperature, light, and water. We grew potted saplings in a warm chamber based on the hottest areas within the Raleigh heat island and in a cooler chamber that was based on the coolest Raleigh temperatures. Within each chamber, half of the trees received daily water so the potting media never dried. Media of the other half was saturated only once it had dried to 5% moisture. This is very dry but is analogous to soil moisture levels we have measured around Raleigh. This regimen simulated the drastic fluctuations urban trees experience between wet and dry conditions. Finally, we infested half the trees in each water condition with lecanium scales. Now we had hot and cool trees that were drought-stressed, with and without scales, and watered, with and without scales. With all those combinations, we hoped to unravel how temperature and drought affected scales and how all three factors combined to affect trees.

The results of this work spoke both to the resilience of trees and to how much we abuse them. It turns out that our willow oaks could withstand high temperatures and even grew more when it was warmer. The trees could even withstand drought with minimal negative effects. Scales alone had no real impact on tree growth, even at the very high densities like we see on urban trees.

However, when we looked at the combinations of stresses—trees that were subject to heat and drought or drought and scales—things began to change. Two stressors, particularly heat and drought, noticeably reduced tree growth in terms of leaf area and biomass. It is easy to think of the urban trees you may manage as being subjected to these two stresses; however, add scales to the mix and trees performed miserably. Leaf area and biomass of hot and dry trees declined as scale density increased. In the end, hot, wet trees were unaffected by scales and acquired twice the leaf area and 50% more biomass than hot, dry trees with high scale density. So, whereas trees have evolved with and are resilient to stress, the continuous application of multiple stresses is not something which they can endure.

Red maple in poor condition infested with gloomy scales.

Adult oak lecanium scales on willow oak swollen with eggs; one is open to reveal eggs inside.

This is the situation of many urban trees. In fact, we conducted a field experiment on established urban trees to help corroborate what we found in the lab experiment. Basal area growth was least on trees subjected to heat and drought stress, and these trees also tended to have higher scale abundance. And by the way, we have repeatedly seen higher lecanium scale survival on hot trees in growth-chamber experiments. As the heat and drought get worse, the scales do too.

Our work suggests that many trees are struggling because stress comes in threes (at least). When certain tree species, like red maples and willow oaks, are planted in parking lots or other areas with a lot of impervious cover, the heat and drought combine to increase pest presence and decrease tree growth and condition. Putting the right tree in the right place will go a long way toward improving tree health—but you already know that. Often, you probably don't decide where trees are planted but have to manage their health after the fact. In this case, watering can help. It sounds simple, I know, but in the experiment we conducted, frequent watering went a long way toward reducing scale population growth and increasing tree photosynthesis and growth. You can also try to reduce scale insect abundance. Both scales we studied are notoriously difficult to manage, but relatively safe, inexpensive tools like horticultural oils and insecticidal soaps can help. These tools won't eliminate the scales but can reduce their abundance. Finally, heat is a major stress that is only getting worse as cities get bigger and the general climate warms. Maintaining dense tree canopy is one of the only ways to counter the urban heat island effect. The more trees in a city, the cooler the city will be, and the better the trees will perform. A good vicious cycle.

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To read more about tree response to warming, read "Water availability drives urban tree growth response to herbivory and warming" (Emily K. Meineke and Steven D. Frank), published in the *Journal of Applied Ecology*. 2018. DOI: 10.1111/1365-2664.13130.