Final Report

Consequences of Urbanization and Climate Change on Human and Ecosystem Health

1. ADMINISTRATIVE:

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2. PUBLIC SUMMARY:

Urban forests provide well-documented environmental and societal benefits valued at more than four billion dollars per year in the United States. As cities expand onto land once occupied by rural forests, urban trees take on an even more vital role in mitigating global climate change, conserving biodiversity, and protecting human health. Maintaining the health of trees is challenging in cities and in forests under climate change because of tree stress and pests. Unhealthy trees do not provide adequate ecosystem services or conservation value compared to healthy trees. In this work we found that exotic trees can remain healthy and maintain biodiversity of arthropods (e.g. spiders and insects) that is similar to native trees, and in stressful locations exotic trees performed better. This information can help resource managers select the best tree species for different locations and goals. We also found that native insects can become invasive pests when exposed to the urban heat island effect or climate warming. As these pests become more abundant and expand their range they could threaten the health of forests. Scientists and resource managers can use our results to predict which species may become pests with climate change and can use cities as laboratories for understanding the effects of climate change.

3. TECHNICAL SUMMARY:

1. Determine tree (and arthropod) characteristics that affect tree-dependent biodiversity, tree herbivory, and resilience of both trees and biodiversity to warming.

We conducted three experiments to test the standard ecological paradigm that native trees will host greater arthropod diversity than exotic trees. In two experiments we compared arthropod diversity and pest density on native and exotic congeners of *Quercus* and *Acer*. The results of both experiments show that, contrary to our hypotheses, exotic species often host as many arthropod species as native congeners and sometimes more. This is particularly evident among predators and parasitoids which are critical to ecosystem stability and pest control. Predators like spiders are also among the most nutritious prey for vertebrates like birds. Exotic trees also sustained high arthropod diversity across an urban gradient of increasing impervious surface cover, temperature, and stress. Diversity on native species declined with urbanization as their arthropod communities became dominated by damaging pests like scale insects. In contrast, since exotic trees are less susceptible to pests they were able to sustain greater diversity. In a third experiment we compared congeners of many shrubs and trees planted to simulate an urban yard. Here too exotic species sustained as much arthropod diversity as native species. The implications of this new knowledge are that scientists and managers need to consider a paradigm shift about the conservation value of exotic species as long as they are not invasive. The conservation value of exotic species becomes greater in urban and disturbed areas where many natives do not thrive and succumb to pests.

The other tree characteristic we studied was tree genotypes as wild type or cultivars. We measured scale density and photosynthesis on red maple wildtype trees, cultivars, and hybrids of red maple and silver maple all of which are commonly used in urban landscapes and even restoration projects. On urban trees gloomy scale (*Melanaspis tenebricosa*) density was lowest on wildtype trees and an order of magnitude higher on cultivar and hybrid trees. Scale density on these trees reached levels known from previous work to be damaging to trees and services. In another experiment we grew red maple wildtype trees and cultivars in pots and infested them with gloomy scales. Trees were assigned to a high water treatment or low water treatment to mimic drought. Scale density was again highest on cultivar and hybrid trees but increased on wildtype trees under drought stress. This suggests even wildtype trees in forests which are less susceptible to pests can become susceptible under climate change. In both experiments measurements of photosynthesis, stomatal conductance, and water use efficiency varied with tree type and season but wildtype trees tended to have greater water use efficiency suggesting a greater ability to withstand changing precipitation regimens over time.

2. Understand how urbanization (and heat) influences pest populations in order to predict future distributions of pests (and loss of biodiversity) in natural forests.
We conducted multiple experiments and surveys to determine how urbanization and temperature affect pest distributions, particularly gloomy scale and oak lecanium scale (*Parthenolecanium quercifex*). Previous work showed that both of these scales reach damaging densities on trees as temperature increases by about 2C. Therefore, we studied these species for their potential to be 'sleeper species' – previously innocuous species that become pests with environmental change. In one experiment we surveyed gloomy scale density across a latitudinal gradient from the northern to southern edges of its range. We found density increased in all cities as impervious surface and temperature increased and that densities were highest in the middle of its range. In laboratory experiments we confirmed that the northern distribution is limited by cold temperatures in winter and that gloomy scale could live in cities north of its typical range due to the urban heat island effect. In another field experiment we confirmed the role of temperature in gloomy scale density in urban landscapes and forests in Raleigh and at the edge of their range in Newark, DE. Gloomy scale densities are higher in forests in Raleigh than Newark, which could increase as the climate warms. Through this research we established the use of cities as laboratories to simulate climate change in a synthesis paper since many insect and plant responses in cities are congruent with their responses to warming in natural areas. We also established the potential of innocuous native insects to become pests – sleeper species – through a synthesis paper of research on scale insects.

3. Integrate effects of warming and urbanization on tree health with effects on human health
We convened a conference titled 'Healthy Trees Healthy People' to discuss the ways in which climate, urbanization, and other factors influence tree health and the health of people. There were 15 participants from multiple universities, non-profits, the tree care industry, and government agencies.

4. PURPOSE AND OBJECTIVES:

1. Determine tree (and arthropod) characteristics that affect tree-dependent biodiversity, tree herbivory, and resilience of both trees and biodiversity to warming.
Rationale*:* In previous research we established that heat increases the abundance of two scale species on two tree species and that this reduces tree health. To establish the generality of this response by pests, to predict consequences for arthropod diversity, and to develop management strategies we need information on which arthropod and tree species respond positively, negatively, or neutrally to elevated temperature. Knowledge gained in this objective helps resource managers select tree species and genotypes and establishes the conservation potential of some exotic but non-invasive tree species in urban areas. This objective was achieved.

2. Understand how urbanization (and heat) influences pest populations in order to predict future distributions of pests (and loss of biodiversity) in natural forests.
Rationale*:* For centuries cities have had environmental conditions such as higher temperatures and CO_2, predicted to occur in natural areas by the end of this century. Thus, cities could serve as valuable indicators of which pest species will thrive and damage rural forests. Previously, we documented congruence in the

response of scale insects to urban warming and natural climate fluctuations. In objective 1 we focused on two native pests to document range expansion to cities and to document ecological mechanisms for range expansion and consequences for natural forests. This objective will inform the decision analytic framework by reducing uncertainty about which pest distributions will change and damage natural forests as a result of climate change. Confirming the generality of our 'cities as sentinels' hypothesis will lead to better pest management in cities and conservation areas. Predicting which pests are expanding their range and how fast will buy valuable time for land managers to implement proactive rather than reactive conservation strategies. This objective was achieved.

3. Integrate effects of warming and urbanization on tree health with effects on human health
Rationale*:* There is empirical evidence that trees and other vegetation can reduce temperature and pollutants so trees provide a direct mechanism for reducing known environmental effects on human health. Unfortunately, climate scientists, ecologists, social scientists, and health professionals rarely collaborate. We will convene working group including members of multiple institutions and multiple departments within NCSU. The objective of this multidisciplinary group will be to synthesize research in urban ecology, global change, forest health, human health, and environmental justice, which until now have functioned in isolation. By joining these groups together we will help identify connections that could lead to multiple environmental, conservation, and human health goals. This objective was achieved.

5. ORGANIZATION AND APPROACH:

Objective 1: We conducted three experiments to test the hypothesis that native trees will host greater arthropod diversity than exotic trees. In two experiments we compared arthropod diversity and pest density on native and exotic congeners of *Quercus* and *Acer*. Our approach to the first experiment was to sample maple and oak congeners on and near the NCSU campus to maintain relatively constant conditions of urbanization. Arthropods were counted by collecting branch samples to count scale insects and with yellow sticky cards for passive sampling of arthropod communities. In the second experiment we also used maple and oak congeners but trees were spread throughout the Raleigh urban heat island with different levels of impervious surface cover. We collected branch samples to count scales and used beat sampling to collect free-living arthropods from foliage. In the final experiment we compared scale density and leaf-level processes on wildtype and cultivated varieties of red maples in urban locations and in an experimental nursery. Scales were counted with branch samples on urban trees and photosynthesis was measured with a LICOR 6400 portable photosynthesis system. In the nursery experiment bareroot trees were planted in plastic containers and infested with gloomy scales. After one year of population growth we counted scales on each tree then imposed watering treatments of high or low water. These treatments were maintained for two years after which scales were counted again and leaf-level processes of photosynthesis, stomatal conductance, and water use efficiency were measured.

Objective 2: We studied gloomy scales and lecanium scales for their potential to be 'sleeper species' – previously innocuous species that become pests with environmental change. In one experiment we surveyed gloomy scale density across a latitudinal gradient from the northern to southern edges of its range. To achieve the we visited eight cities in the eastern USA (Asheville, NC, Atlanta, GA, Charlotte, NC, Gainesville, FL, Knoxville, TN, Newark, DE, Raleigh, NC, and Savannah, GA) that encompassed the southern distribution of A. rubrum and the known latitudinal extent of *M. tenebricosa*. We collected branches from 30 trees in each city to count gloomy scales. In laboratory experiments we subjected gloomy scales from Raleigh, Newark, and Gainesville to freezing temperatures at multiple durations to determine the lower thermal limit and thus latitude it could survive. In another field experiment we collected branches from forest and landscape trees to determine scale density and relationship to temperature in urban and forest situations in Raleigh and in Newark.

Objective 3: We invited participants from multiple disciplines to attend and recorded notes of the discussions.

6. PROJECT RESULTS:

1. Determine tree (and arthropod) characteristics that affect tree-dependent biodiversity, tree herbivory, and resilience of both trees and biodiversity to warming.
We conducted three experiments to test the standard ecological paradigm that native trees will host greater arthropod diversity than exotic trees. In two experiments we compared arthropod diversity and pest density on native and exotic congeners of *Quercus* and *Acer*. The results of both experiments show that, contrary to our hypotheses, exotic species often host as many arthropod species as native congeners and sometimes more. For example, in 2012 neither predator nor parasitoid abundance differed among native and exotic *Acer* congeners but in 2016 a native species, *A. saccharum*, had the least of both groups. A native, *Q. phellos*, had significantly more predators and parasitoids in 2012 than its native and exotic congeners but no differences in 2016.

In the second experiment, the insect community on maples varied significantly with tree species and nearly significantly with coarse vegetation. All pairwise comparisons of maple species showed different insect communities except the comparison between *A. buergerianum* and *A. x freemanii*. *Aphididae* (Hemiptera) and *Thripidae* (Thysanoptera) had the strongest responses to tree species. *Aphididae* abundance was higher on *A. saccharum* than on *A. buergerianum* or *A. platanoides*. *Thripidae* abundance was lower on *A. platanoides* than on *A. buergerianum* and *A.* x freemanii and was also lower at sites with more coarse vegetation cover.

Oaks were divided into two groups, a high coarse vegetation group and a low coarse vegetation group, after we detected a significant species by coarse vegetation interaction. In the low coarse vegetation group, there was not a significant effect of tree species. In the high coarse vegetation group, insect communities differed by tree species, with *Q. alba* having a different community than *Q. lyrata* or *Q. palustris*.

The other tree characteristic we studied was tree genotypes as wild type or cultivars. We measured scale density and photosynthesis on red maple wildtype trees, cultivars, and hybrids of red maple and silver maple, all of which are commonly used in urban landscapes and even restoration projects. Leaf-level gas exchange was significantly affected by seedling type, treatment, and month. Overall, mean rates of photosynthesis were highest in April, followed by September, and lowest in June. Photosynthesis rates were greater in the high water treatment than the low water treatment, and this difference was most apparent in April. We found a significant seedling type × month interaction, where differences in photosynthetic rates between seedling types were greater in April than in June or September, with wildtype or Summer Red seedlings always having the highest mean photosynthesis rate. Instantaneous water use efficiency—the ratio of photosynthesis to stomatal conductance—was not affected by water treatment but was significantly affected by a seedling type × month interaction. Summer Red seedlings had the lowest water use efficiency. Similar water use efficiency occurred for Brandywine and wildtype seedlings in April, Brandywine seedlings had higher water use efficiency in June, and wildtype seedlings had higher water use efficiency in September. Gloomy scale abundance did not significantly differ for seedlings in the low water treatment. Compared to the low water treatment, the high water treatment reduced scale abundance on wildtype seedlings but increased scale abundance on Brandywine and Summer Red seedlings.

2. Understand how urbanization (and heat) influences pest populations in order to predict future distributions of pests (and loss of biodiversity) in natural forests.
We conducted multiple experiments and surveys to determine how urbanization and temperature affect pest distributions, particularly gloomy scale and oak lecanium scale. In one experiment we surveyed gloomy scale density across a latitudinal gradient from the northern to southern edges of its range. We found that urban tree health did not vary with latitudinal temperature but was best predicted by local urbanization and herbivore abundance. We did not observe increased herbivore abundance in warmer, lower-latitude cities, but instead herbivore abundance peaked in the mid latitudes of our study. We found density increased in all cities with impervious surface. In another field experiment we confirmed the role of temperature in gloomy scale density in urban landscapes and forests in Raleigh and at the edge of their range in Newark, DE. Trees in forest fragments were 1.3° cooler and had three orders of magnitude fewer *M. tenebricosa* than trees in

ornamental landscapes in Raleigh, NC USA. However, there was no difference in *M. tenebricosa* density between forest and landscape trees in Newark, DE and Philadelphia, PA USA which are 3.95 degrees of latitude higher, and nearer to the northern range extent.

3. Integrate effects of warming and urbanization on tree health with effects on human health
We convened a conference titled 'Healthy Trees Healthy People' to discuss the ways in which climate, urbanization, and other factors influence tree health and the health of people. There were 15 participants from multiple universities, non-profits, the tree care industry, and government agencies.

7. ANALYSIS AND FINDINGS:

The major discovery for Objective 1 was that native and exotic tree species can support similar levels of biodiversity and that native trees become less valuable at highly urban sites due to stress and pests.

The major discovery for *Objective 2* was that an innocuous species can become a pest with climate change and expand its range to the thermal refuge of cities north of its natural range.

The major conclusion of *Objective 3* was that tree preservation and urban forestry are extremely complex issues with many stakeholders. Finding causal relationships between trees and health present many logistical and ethical challenges.

8. CONCLUSIONS AND RECOMMENDATIONS:

Our conclusions and recommendations are that urban trees and urban forest fragments contain significant arthropod biodiversity that supports ecosystem processes and vertebrates at higher trophic levels like birds. Preserving tree canopy cover in urban areas will require a combination of native and exotic species to ensure healthy trees, conservation, and ecosystem services for people. Our second conclusion is that cities can serve as experimental laboratories for climate change research and help identify species that may become invasive with climate change.

9. MANAGEMENT APPLICATIONS AND PRODUCTS:

Our findings will be used to manage urban forests for the benefit of biodiversity and people. We worked with many city personnel who provided tree inventory information, permission to sample trees and logistical support. The North Carolina Urban Forest Council provided an outlet for outreach via presentations and articles in their newsletter.

10. OUTREACH:

Outreach consisted of peer reviewed publications, extension and industry publications, extension presentations, and research presentations, and blog posts on the lab website.

Peer reviewed publications:

1. Frank, S.D. and Just, M.G. (2020) Can cities activate sleeper species and predict future forest pests? A case study of scale insects. *Insects*, 11(3): 142.
2. Lahr, E.C., Backe, K.M.[†], and Frank, S.D. (2020) Intraspecifc variation in morphology, physiology, and ecology of wildtype relative to horticultural varieties of red maple (*Acer rubrum*). *Trees – Structure and Function*, https://doi.org/10.1007/s00468-019-01942-2.
3. Parsons, S.E.[†], Kerner, L.M., and Frank, S.D. (2020) Effects of native and exotic congeners on diversity of invertebrate natural enemies, available spider biomass, and pest control services in residential landscapes.
4. Frank, S.D. (2019) A survey of key arthropod pests on common southeastern street trees. *Arboriculture & Urban Forestry*, 45(5): 155-166.
5. Just, M.G., Long, L.C.[†], Dale, A.G., and Frank, S.D. (2019) Urbanization drives unique latitudinal patterns of insect herbivory and tree condition. *Oikos*. https://doi.org/10.1111/oik.05874. PDF.

6. Frank, S.D., Backe, K.M.[†], McDaniel, C.[*], Green, M., Widney, S., Dunn, R.R. (2019) Exotic urban trees conserve similar natural enemy communities to native congeners but have fewer pests. *PeerJ*: 7:e6531 https://doi.org/10.7717/peerj.6531.
7. Long, L.C.[†], D'Amico, V., Frank, S.D. (2019) Urban forest fragments buffer trees from warming and pests. *Science of the Total Environment*, 658: 1523-1530.
8. Dale, A.G. and Frank, S.D. (2018) Urban plants and climate drive unique arthropod interactions with unpredictable consequences. *Current Opinion in Insect Science*, 29: 27-33. https://doi.org/10.1016/j.cois.2018.06.001.
9. Just, M.G., Frank, S.D., and Dale, A.G. (2018) Impervious surface thresholds for urban tree site selection. *Urban Forestry & Urban Greening*, 34: 141-146. https://doi.org/10.1016/j.ufug.2018.06.008.
10. Lahr, E.C., Dunn, R.R., and Frank, S.D. (2018) Getting ahead of the curve: cities as surrogates for global change. *Proceedings of the Royal Society B*, 285: 20180643. http://dx.doi.org/10.1098/rspb.2018.0643.
11. Lahr, E.C., Dunn, R.R., and Frank, S.D. (2018) Variation in photosynthesis and stomatal conductance among red maple (*Acer rubrum*) urban planted cultivars and wildtype trees in the southeastern United States. *PLOS One*: 13(5): e0197866.
12. Dale, A.G.[†], Frank, S.D. (2017) Warming and drought combine to increase pest insect fitness on urban trees. *PLoS ONE* 12(3): e0173844. doi:10.1371/journal.pone.0173844.
13. Meineke, E.K. and Frank, S.D. (2018) Water availability drives urban tree growth responses to herbivory and warming. *Journal of Applied Ecology*, DOI: 10.1111/1365-2664.13130.
14. Youngsteadt,E., Ernst, A.F., Dunn, R.R., Frank, S.D. (2016) Responses of arthropod populations to warming depend on latitude: evidence from urban heat islands. *Global Change Biology*, doi: 10.1111/gcb.13550
15. Meineke, E.K.[†], Youngsteadt, E.K., Dunn, R.R., Frank, S.D. (2016) Urban warming reduces aboveground carbon storage. *Proceedings of the Royal Society – B*, 283: 20161574.

Research presentations:

1. Frank, S.D. 2018. Can forests take the heat? Effects of warming on tree pests and services. Texas A&M University, Entomology Department Seminar.
2. Frank, S.D. 2018. Cities as sentinels of warming effects on forests. Southeast Climate Science Center.
3. Frank, S.D. 2018. Ecology, IPM, and Extension in urban landscapes. National Turfgrass Entomology Workshop.
4. Frank, S.D. 2018. Can forests take the heat? Effects of warming on tree pests and services. Oregon State University, Botany and Plant Pathology Department Seminar.
5. Youngsteadt, E., A. Hamblin, and S. D. Frank. 2018. Too hot downtown? The effect of urban warming on bee communities. Protecting Pollinators in Urban Landscapes Conference. Traverse City, MI.
6. Frank, S.D. 2017. Can forests take the heat? Effects of warming on tree pests and services. University of Oregon, Ecology and Evolution seminar series.
7. Frank, S.D. 2017. Can forests take the heat? Effects of warming on tree pests and health. Universidade de Lisboa, Instituto Superior de Agronomia, Lisbon, Portugal.
8. Frank, S.D. 2017. Can forests take the heat? Effects of warming on tree pests and health. University of Delaware, Department of Entomology and Wildlife Ecology Seminar.
9. Frank, S.D. 2017. Can forests take the heat? Effects of warming on tree pests and health. Virginia Commonwealth University, Biology Department Seminar.
10. Meineke, EK, Youngsteadt, EK, Dunn, RR, Frank, SD. 2016. Insect pests and the future of warmer urban trees. Center for Macroecology, Evolution, and Climate departmental seminar series. University of Copenhagen.
11. Frank, S.D., Dale, A. G., Meineke, E. K., Youngsteadt. 2016. Can forests take the heat? Effects of warming on tree pests and health. National Forum on Climate and Pests. National Academy of Sciences, Washington DC.
12. Dale, AG, Frank, SD. 2016. Effects of Urbanization on Insect Pests and their Street Tree Hosts. USGS Wetland and Aquatic Research Center seminar series. Gainesville, FL.

13. Frank, S.D. 2016. Can forests take the heat? Effects of warming on tree pests and health. North Carolina State University, Department of Plant Pathology.
14. Frank, S.D. 2016. Urban Trees: Managing the Urban Forest as an Experiential Ecosystem. Growing In Place Symposium, Natural Learning Initiative, Raleigh, NC.
15. Frank, S.D. 2016. New pests on the horizon: warming transforms native herbivores into invasive tree pests. USDA Forest Service Interagency Research Forum on Invasive Species, Annapolis, MD.
16. Frank, S.D. 2015. Can forests take the heat? Effects of warming on tree pests and health. University of Maryland, Department of Entomology seminar series.
17. Frank, S.D. 2015. Can forests take the heat? Effects of warming on tree pests and health. North Carolina State University, Department of Forestry seminar series.
18. Frank, S.D. 2015. Can forests take the heat? Effects of warming on tree pests and health. University of Kentucky, Department of Entomology seminar series.
19. Frank 2019. Can forests take the heat? Effects of warming on tree pests and services. IUFRO International Congress, Curitiba, Brazil.
20. Backe, K. & Frank, S. 2019. Insects in temperate urban forests: Distributions over space and time. Organized Oral Session - Bridging the Research Community: Whole Systems Approach for Temperate Deciduous Forests. Ecological Society of America annual meeting. Louisville, KY.
21. Lahr, N., Backe, K., Dunn, R., Frank, S. (2019). What urban trees can tell us about forests of the future: Cities as surrogates for the effects of global change. Ecological Society of America annual meeting. Louisville, KY. Frank, S.D. and Bissonette, C. 2019. Do dung beetles remove what urban dogs leave behind? Entomological Society of America, St. Louis, MI.
22. Frank 2019. Can forests take the heat? Effects of warming on tree pests and services. European International Conference on Transforming Urban Systems, Strausborg, France.
23. Frank, S.D. 2018. Effects of warming on scale insects: From street trees to forests. Entomological Society of America, Vancouver, CA.
24. Frank, S.D. 2018. The future of IPM for ornamental plants. 21st Ornamental Workshop on Insects and Diseases, Hendersonville, NC.
25. Frank, S.D. 2018. Cities as sentinels of warming effects on forests. Southeast Climate Science Center Stakeholder Workshop.
26. Frank, S.D. 2017. Urbanization transforms native herbivores into exotic pests. Le Studium Conference on Species Spread in a Warmer and Globalized World, Orléans, France.
27. Long, L.C., Frank, S.D. 2017. Urban forest fragments serve as tree refugia from abiotic stress and insect pests. Forest Entomology Symposium: Entomological Society of America, North Central Branch Meeting, Indianapolis, IN.
28. Meineke, E.K., Youngsteadt, E., Dunn, R.R., Frank, S.D. 2016. Hot in the city: Insect pests and the future of warmer urban trees. Symposium: Plant-Insect interactions in a changing climate, International Congress of Entomology, Orlando, FL.
29. Dale, A.G., Frank, S.D. 2016. The effects of urbanization on insect herbivores and their street tree hosts. Symposium: Plant-Insect interactions in a changing climate, International Congress of Entomology, Orlando, FL.
30. McCluney, K.E, Sabo, J.L., Frank, S.D., Becker, J.E. 2016. Patterns and consequences of variation in arthropod water balance across ecosystems with divergent climate, land-use, and hydrological alteration. International Congress of Entomology, Orlando, FL.
31. Frank, S.D., Dale, A. G., Meineke, E. K., Youngsteadt. 2016. Can forests take the heat? Managing pests and ecosystem services in a warming climate. Symposium: Biological Control Under Climate Change, International Congress of Entomology, Orlando, FL.
32. Youngsteadt, E., Meineke, E.K., Dale A.G., Frank S.D. 2016. Cambio climático en el bosque: Efectos del calentamiento urbano y global en los árboles y sus plagas. Sociedad Colombiana de Entomología, Manizales, Colombia.

33. Meineke, EK, Youngsteadt, EK, Dunn, RR, Frank, SD. 2016. Insect pests and the future of warmer urban trees. P-IE section symposium: Insect-Plant Interactions in a Changing Climate. International Congress of Entomology.
34. Frank, S.D., Dale, A. G., Meineke, E. K., Youngsteadt. 2016. Urban warming increases pest fitness and abundance and reduces tree health. Rediscovering our Urban Forests Symposium, North American Forest Insect Work Conference, Washington DC.
35. Dale, A. G., Meineke, E. K., Youngsteadt, E., Frank, S. D. 2015. Can forests take the heat? Managing pests and ecosystem services under climate change. P-IE section symposium: Effects of Global Climate Change on Species Interactions and Biological Control. Entomological Society of America, Minneapolis, MN.

Extension publications:

1. Frank, S.D. (2019) The vicious cycle of stress. *Arborist News*, February 2019, 28(1): 44-46.
2. Frank, S.D. (2018) Compatible tools. *Nursery Management*, December 2018.
3. Frank, S.D. (2018) Keep your cool. *Nursery Management,* September 2018.
4. Frank, S.D. (2018) Defeat the defoliators. *Nursery Management,* July 2018.
5. Frank, S.D. (2017) How to recognize and manage scale insects. *Landscape Management,* July 2017.
6. Frank, S.D. (2017) Take Up Arms. *Nursery Management,* 81:4.
7. Frank, S.D. (2017) Put Maples in Their Place. *Grower Talks,* July 2017.
8. Frank, S.D. (2016) Spying for Scales. *Grower Talks,* 80:8.
9. Frank, S.D. & A.G. Dale (2016) Impervious surface thresholds to select planting sites. *North Carolina Urban Forest Council Newsletter*, August.
10. Frank, S.D. (2015) Know your enemy: armored scale biology & IPM. *GrowerTalks,* 79:4.
11. Frank, S.D., Dale, A.G., Just, M., Youngsteadt, E.K. 2017. Implementing impervious surface thresholds with the 'Pace to Plant technique in the Southeast. Power Point presentation. http://ecoipm.org/wp-content/uploads/PtoP_Pwrpnt_regional.pptx
12. Frank, S.D., Dale, A.G., Just, M., Youngsteadt, E.K. 2017. Impervious surface thresholds and a technique for guiding red maple planting in the Southeast. http://ecoipm.org/wp-content/uploads/PtoP_ExtHandout_regional.pdf
13. Frank, S.D., Dale, A.G., Youngsteadt, E.K. 2016. Impervious Surface Thresholds for Sustainable Urban Tree Planting and Landscape Design. https://content.ces.ncsu.edu/impervious-surface-thresholds-for-sustainable-urban-tree-planting-and-landscape-design
14. Frank, S.D., Dale, A.G., Youngsteadt, E.K. 2016. Measuring Impervious Surface Cover with the Pace to Plant Technique. https://content.ces.ncsu.edu/measuring-impervious-surface-cover-with-the-pace-to-plant-technique
15. Frank, S.D., Dale, A.G., Youngsteadt, E.K. 2017. Implementing impervious surface thresholds with the 'Pace to Plant technique in the Southeast. Power Point presentation. http://ecoipm.org/wp-content/uploads/PtoP_Pwrpnt_Raleigh_Original.pptx
16. Frank, S.D., Dale, A.G., Youngsteadt, E.K. 2016. Impervious surface thresholds and a technique for guiding red maple planting. http://ecoipm.org/wp-content/uploads/PtoP_ExtHandout_AGDale_revisedauthors.pdf
17. Dale, A.G., Frank, S.D**.** 2015. Maple spider mite. NC State Extension. http://content.ces.ncsu.edu/maple-spider-mite-oligonychus-aceris-shimer-acariformes-tetranychidae/
18. Dale, A.G., Frank, S.D. 2015. Japanese maple scale. NC State Extension. http://content.ces.ncsu.edu/japanese-maple-scale-lopholeucaspis-japonica-cockerell-hemiptera-diaspididae/

Extension presentations:

1. November 5, 2019. Can forests take the heat? Duke University ENCORE lecture series. 100 attendees.
2. September 26, 2019. The native plant paradox: Costs and benefits of planting native trees. NC Arboretum IPM Symposium. ~150 attendees.
3. September 6, 2019. Pest and beneficial insects in your garden. JC Raulston Arboretum. 150 attendees.

4. July 16, 2019. How the urban heat island effect increases pests. Raleigh Citizen Advisory Council. ~30 attendees.
5. May 30, 2019. New pests of ornamental trees and shrubs. Pitt County Landscape conference. 30 attenddees.
6. March 26, 2019. IPM for ambrosia beetles and scale insects. Johnston Co. Nursery Association. ~30 attendees.
7. February 12, 2019. IPM for ambrosia beetles and scale insects. Eastern NC Nursery Conference, Wilson, NC. ~100 attendees.
8. February 5, 2019. Scale insect management on trees and shrubs. Regional Turf and Landscape Conference, Wilmington, NC. 64 attendees.
9. January 31, 2019. Crape myrtle bark scale and other new and emerging pests. Lenoir Green Industry Program. 100 attendees.
10. January 23, 2019. Crape myrtle bark scale and other new and emerging pests. Carolina Green Industry Network. Union County. 600 attendees.
11. January 16, 2019. Select planting sites to reduce tree stress and pest infestations. NCNLA Green and Growin' Show. Greensboro, NC. 500 attendees.
12. October 17, 2018. Can urban tree pests take the heat? Rainbow Tree Annual Seminar. Stowe Botanical Garden. 41 attendees.
13. September 27, 2018. Can urban forests take the heat? Horticulture Industry IPM Symposium. NC Arboretum.
14. June 27, 2018. Assessment and predictions of tree risk to urban conditions and scale insect Infestations. Landscape Color and Professional Field Day. Raleigh, NC. ~ 100 people. *Presenter* Just, M.G.
15. March 16, 2017. Assessing and managing tree risk of scale infestations. Pittsboro Landscape Conference, Pittsboro, NC.
16. June 29, 2016. Managing pests and protecting pollinators in urban environments. Landscape Color and Professional Field Day, Raleigh, NC.
17. March 8, 2016. Assessing and managing tree risk of scale infestations. Lenoir, NC.
18. February 24, 2016. Assessing and managing tree risk of scale infestations. Brunswick Co. ProDay, Castle Hayne, NC.
19. February 23, 2016. Assessing and managing tree risk of scale infestations. Eastern North Carolina Landscape Conference, Rocky Mount, NC.
20. February 2, 2016. Assessing and managing tree risk of scale infestations. Chatham Landscape Conference, Pittsboro, NC.
21. January 26, 2016. Assessing and managing tree risk of scale infestations. Carolina Green Industry Network Landscape Seminar, Union County, NC.
22. January 12, 2016. Assessing and managing tree risk of scale infestations. Green and Growin' Trade Show Greensboro, NC.
23. December 9, 2015. Scale insect identification and management. Carolina Vegetation Management Association, Greensboro, NC.
24. October 27, 2015. Integrated pest management of scale insects. Ornamental and Turf Workshop, Wayne County, NC.
25. October 1, 2015. Effects of urbanization on pests and pollinators. NC IPM Symposium, NC Arboretum, Asheville, NC.
26. June 9, 2015. Identification and management of scales on urban trees. NCFS Workshop, Wilson, NC.
27. June 2015. Dale, A. G., Frank, S. D. What's happening on our streets: How cities affect insect pests in urban forests. Cape Fear Backyard Naturalist Program. Wilmington, NC.
28. June 2015. Meineke, E. K., Frank, S. D. Hot in the City: Effects of urban warming on street trees and their pests. Cape Fear Backyard Naturalist Program. Wilmington, NC.
29. January 6, 2015. Managing new pests and old pals in the landscape. Green and Growin' Trade Show, Greensboro, NC.