Integrating the Effects of Global and Local Climate Change on Wildlife in North America &
Tree Eaters: Predicting the Response of Herbivores to the Integrated Effects of Urban and Global Change

Final Memo
October 2015

1. ADMINISTRATIVE: Please include name(s) and contact information of the Principal Investigator(s), Agency or Institution, project title, agreement number, date of report, period of performance (including no cost extensions), and actual total cost.

Recipients:
Robert R. Dunn, Department of Applied Ecology, NC State University
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Project Titles:
Integrating the Effects of Global and Local Climate Change on Wildlife in North America and *Tree Eaters: Predicting the response of herbivores to the integrated effects of urban and global change*

Agreement Number:
Tree Eaters: G13AC00405
Integrating the Effects: G11AC20471

Date of Report: October 2015

Period of Time Covered: 2011-2015

Actual Total Cost (both projects): $309,978 (Tree Eaters: $74,978 and Integrating The Effects: $235,000)

2. PUBLIC SUMMARY:

Climate in the southeastern U.S. is predicted to be changing at a slower rate than other parts of North America; however, land use change associated with urbanization is having a significant effect on wildlife populations and habitat availability. We sought to understand the effect of global warming on both beneficial and pest insects of trees. We used urban warming as a proxy for global warming in as much as many cities have already warmed as much, due to heat island effects, as they are expected

to warm due to climate change by 2050 or even 2100. We were able to develop good predictive models of how warming influences beneficial and pest insects for cities in the Southeast and across the east coast more generally. We were also able to predict how tree health will respond to these changes in insect communities. In addition, by comparing our results to those we garnered from herbarium specimens (many insects can be found on herbarium specimens) we could show that the effects of urban warming match those of climate change through time. In short, a subset of pests is likely to get far worse with warming and this effect is likely to be most pronounced in the southeast. A second body of work built on these discoveries to consider how to protect trees and forests from the pests that do better with warming. Work continues to be focused on the importance of which trees are present (or planted) and the diversity of those trees.

3. TECHNICAL SUMMARY:

Through a series of more than twelve scientific papers we established that insect pests become more abundant with urban warming, that that abundance is partially due to escape from their parasitoids, that butterflies alter their flight phenology in response to urban warming, that the effect of urban warming is contingent on background temperatures (urban warming has a bigger and different effect where conditions are already warm, e.g., in the southeast) and that the influence of urban warming on insects leads to indirect effects on plant health, though these are in addition to the direct effects of warming on plant health. Overall we found warming and pests combine to reduce tree function and services including carbon sequestration and environmental cooling. In considering large-scale geographic sampling and herbarium specimens, we found that urban warming is a useful proxy for global warming. Changes through time in temperature have the same effect that changes across the geography of a city have, across space. As a result, all of the above results are likely to hold as much for global warming as for urban warming. However, this is not to say the effects of urban warming are unimportant in and of themselves. Through a collaboration with Adam Terando we were able to show that urbanization will increase in coming years in the Southeast, leading to a massive city we have called Charlanta where average temperatures are likely to be extreme due to the mix of urban and global warming. Nor is it to fail to note that the ability to use herbarium specimens as way to study changes in pest insect abundance is a novel approach, one that is likely to spread among institutions in ways that leverage the value of herbaria. Collectively, these advances represent perhaps the first significant step forward in our understanding of the influence of urban heat islands on the ecology of insects and a major step forward in using urban heat islands as a proxy for hard to study aspects of global warming.

4. PURPOSE AND OBJECTIVES:

The original objectives were to understand how urban warming influences insect pests and how this varies as a function of geography. We have addressed this objective well and more comprehensively than proposed in the project proposal. In addition, we sought to determine what other factors, including the background composition and diversity of trees and other species might mitigate the influence of urban (and global warming). This latter work is ongoing but when fully completed will also be far more ambitious than initially laid out in the proposal. In short, the only difference from the original proposal is that we did more ambitious work than indicated.

5. ORGANIZATION AND APPROACH:

The research was achieved through collaboration among many members of the Dunn, Frank and Haddad labs. Because of the large size of these labs, this project was able to leverage expertise and additional resources from three departments, two colleges and grants from USDA, NSF (6 different grants), DOE, and USDA.

6. PROJECT RESULTS:

Through a series of more than twelve scientific papers we established that insect pests become more abundant with urban warming, that that abundance is partially due to escape from their parasitoids, that butterflies alter their flight phenology in response to urban warming, that the effect of urban warming is contingent on background temperatures (urban warming has a bigger and different effect where conditions are already warm, e.g., in the southeast) and that the influence of urban warming on insects leads to indirect effects on plant health, though these are in addition to the direct effects of warming on plant health. In considering large-scale geographic sampling and herbarium specimens, we found that urban warming is a useful proxy for global warming. Changes through time in temperature have the same effect that changes across the geography of a city have, across space. As a result, all of the above results are likely to hold as much for global warming as for urban warming. However, this is not to say the effects of urban warming are unimportant in and of themselves. Through a collaboration with Adam Terando we were able to show that urbanization will increase in coming years in the Southeast, leading to a massive city we have called Charlanta where average temperatures are likely to be extreme due to the mix of urban and global warming. Nor is it to fail to note that the ability to use herbarium specimens, as a way to study changes in pest insect abundance is a novel

approach, one that is likely to spread among institutions in ways that leverage the value of herbaria. Collectively, these advances represent perhaps the first significant step forward in our understanding of the influence of urban heat islands on the ecology of insects and a major step forward in using urban heat islands as a proxy for hard to study aspects of global warming.

7. ANALYSIS AND FINDINGS:

In addition to the above, we had three major innovations in approaches. First, we have pioneered the study of the effects of urban warming on insect ecology. Second, we established urban warming as a useful proxy for global warming (particularly when paired with experiments, models, etc…). Third, we have pioneered the use of herbarium specimens to track the effects of changes in climate on herbivory. Each of these has the potential to launch many new studies, insights and actionable discoveries.

8. CONCLUSIONS AND RECOMMENDATIONS:

Of course, if you ask the PIs of a grant what to do next they will say that they need more funding. In this, we agree. The next step is to move from our basic insights into what is going on in terms of the effects of warming on insects to key next steps. This requires more funding. Here are the key next steps for funding.

1-Move from an understanding of the influence of warming on insects to a plan for which trees should be planted in light of the influence of warming on insects (underway, led by Steve Frank).

2-Identify, based on our models of the influence of tree composition and diversity on susceptibility to warming the forests that are at the most risk in the near future. In practice, these will be the forests where models of trees on their own are the least useful. In fact, given the strong influence we see of tree feeding insects under warming we suspect that in many regions of the southeast, models of trees and forests (and their distribution, conservation, etc…) under warming are incomplete when insects are not taken into account. Thus, our understanding of how warming and pests interact to affect tree growth and carbon sequestration could be incorporated into models of how forests will mediate warming.

3-Scale up the study of herbarium specimens to better understand the nuances of how climate change influenced tree herbivores in the past. Here, a partnership with hundreds of herbaria would be easy and would yield major discoveries, contingent funding.

9. MANAGEMENT APPLICATIONS AND PRODUCTS:

Our findings have two primary implications for management changes. First, warming increases arthropod pests on trees. This information could be used to increase forest monitoring for early detection of emerging pest problems. The scale insects we focused on are native insects that occur in very low, almost undetectable densities, in forests but become 300 times more abundant with 2-3 Celsius of warming. Thus, monitoring chronic pests in addition to dramatic pest outbreaks could help catch problems early. Another way our project could affect management is by informing models of how warming will affect trees and the services they provide. Many models and experiments predict trees will grow more with warming. In the absence of pests this may be true. However, we found that since warming also increases pests trees actually grow less in warmer climates and sequester less carbon. This effect increases dramatically under drought conditions. Thus further research could focus on developing new models that incorporate these complex biotic and abiotic effects.

10. OUTREACH:

Peer-reviewed articles and reports

Youngsteadt, E., Henderson*, R. C., Savage, A. M., Ernst, A. F., Dunn, R. R. and **Frank, S. D.** (2014) Habitat and species identity, not diversity, predict the extent of refuse consumption by urban arthropods. *Global Change Biology*. doi: 10.1111/gcb.12791.

Meineke, E. K.†, Dunn, R. R., **Frank, S. D.** (2014) Early pest development and loss of biological control are associated with urban warming. *Biology Letters*. doi: 10.1098/rsbl.2014.0586.

Youngsteadt, E., Dale, A. G., Terando, A. J., Dunn, R. R., and **Frank, S. D.** 2015. Do cities simulate climate change? A comparison of herbivore response to urban and global warming.*Global Change Biology* 21:97-105.

Dale A.G.† and **Frank S.D.** 2014. The effects of urban warming on herbivore abundance and street tree condition. PLoS ONE 9(7): e102996.

Frank, S.D. 2014. Bad neighbors: urban habitats increase cankerworm damage to non-host understory plants. *Urban Ecosystems*.

Dale†, A.G. and **Frank, S.D.** 2014. Urban warming trumps natural enemy regulation of herbivorous pests. *Ecological Applications*.

Meineke, E.K.†, Dunn, R.R., Sexton, J. and **Frank, S.D.** 2013. Urban warming drives insect pest abundance on street trees. *PLoS One*.

Project-related websites

A Bug in a Bug in a Tree in the City

Designed by Lynn Fellman. An illustrated slideshow conceived by Rob Dunn and based on the research of Emily Meineke and Elsa Youngsteadt on scale insects and urban ecology. http://robdunnlab.com/science-portfolio/a-bug-in-a-bug-in-a-tree-in-the-city/

Scientists Create Tiny Zones of Climate Change

National Geographic produced a video about our big warming chamber experiments. Narrated by Rob Dunn and Lauren Nichols.
http://video.nationalgeographic.com/video/news/150727-news-warming-chambers-vin

Big City Social Life

by Eleanor Spicer Rice
As urbanization spreads and city structures replace many social insect colonies' natural habitats, these insects still manage to survive—and even thrive. The secret to their success? A fluid colony structure, which guards against big-city dangers.
http://robdunnlab.com/science-portfolio/big-city-social-life/?portfolioID=71

My Urban Walk

Map Created by Lauren Nichols and Designed by Neil McCoy. A map that displays the surface temperatures of Rob's daily walk from home to campus. Read more about it in this post on Your Wild Life.
http://www.yourwildlife.org/2014/06/hot-in-the-hood/

http://robdunnlab.com/science-portfolio/my-urban-walk/?portfolioID=71

The Rise of CHARLANTA

Adam Terando projected human city expansion based on his social insect model of city growth into the future. He used his rules to predict what would happen in the southeastern United States if urbanization continued to expand according to these rules of growth. In this map what you see is that the area from Charlotte, North Carolina to Atlanta, Georgia becomes one giant city. Raleigh and Durham, North Carolina are then a separate megacity connected to that much larger one.
http://www.yourwildlife.org/2014/07/the-rise-of-charlanta/

Additional Media Coverage from *The Southern Megalopolis: Using the Past to Predict the Future of Urban Sprawl in the Southeast U.S*

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0102261

USGS issued press release, joint with NC State University:
http://www.usgs.gov/newsroom/article.asp?ID=3943#.U9ZtYoBdVgY

The Washington Post:
http://www.washingtonpost.com/blogs/wonkblog/wp/2014/07/30/what-the-rapidly-urbanizing-southeast-could-look-like-come-2060/?wpisrc=nl_wnkpm

The Washington Post (2nd article):
http://www.washingtonpost.com/national/health-science/southeast-could-become-an-overdeveloped-megalopolis-in-the-next-half-century/2014/08/09/27a5ce98-1819-11e4-9349-84d4a85be981_story.html

The Atlantic's City Lab:
http://www.citylab.com/housing/2014/07/by-2060-the-american-south-could-be-three-times-as-urbanized/375017/

NPR-WUNC:
http://wunc.org/post/megalopolis-stretch-raleigh-atlanta

NPR-WABE-Atlanta. Live radio interview with first author, Adam Terando:
http://wabe.org/post/could-explosive-growth-lead-southern-megalopolis

Atlanta Magazine:
http://www.atlantamagazine.com/agenda/2014/07/25/behold-the-sprawl-of-2060-when-atlanta-and-charlotte-finally-converge#sthash.oj3i92rp.dpuf

Atlanta Business Chronicle:
http://www.11alive.com/story/news/local/2014/07/31/southern-megalopolis/13396977/

Conservation Magazine:
http://conservationmagazine.org/2014/08/just-how-far-will-urban-sprawl-spread/

The Weather Channel:
http://www.weather.com/video/bad-news-for-millions-across-south-51830

Triangle Business Journal:
http://www.bizjournals.com/triangle/blog/techflash/2014/07/how-a-2060-megalopolis-could-change-raleigh.html

The Post and Courier:
http://www.postandcourier.com/article/20140806/PC1610/140809592/1356/a-new-warning-for-the-south-grow-smarter

Raleigh Public Record:
http://raleighpublicrecord.org/news/2014/08/04/se-raleigh-food-desert-finally-getting-a-grocery-store/

Enviromental and Energy Study Institute:
http://www.eesi.org/articles/view/usgs-finds-growing-urban-sprawl-in-southeast-rivals-threat-of-climate-chang

Goupstate.com
http://www.goupstate.com/article/20140816/ARTICLES/140819748/1112?p=1&tc=pg

Sustainability: Science, Practice and Policy Journal Blog
http://ssppjournal.blogspot.com/2014/08/a-sprawling-enemy-of-biodiversity.html

Sustainability: Science, Practice and Policy Journal Blog (second post)
http://ssppjournal.blogspot.com/2014/09/sprawl-more-or-less.html

Greenville Journal:
http://greenvillejournal.com/local/3536-future-shock.html

Greenville Journal, editorial:
http://greenvillejournal.com/local/3537-a-warning-the-upstate-should-heed.html

Conference Presentations

1. Frank, S.D., Meineke[†], E.K., Dale[†], A.G., Youngsteadt[§], E., and Dunn, R.R. 2013. Hot in the city: effects of urban heat on the ecology and evolution of urban forest pests. Proceedings of the International Symposium on Biological Control of Arthropods, Pucon, Chile.
2. Frank, S.D. 2014. Can forests take the heat? Effects of warming on tree pests and health. University of Tours, Tours, France.
3. Frank, S.D. 2014. Can forests take the heat? Effects of warming on tree pests and health. Oklahoma State University, Department of Entomology seminar series.
4. Frank, S.D. 2014. Urban and global warming affect pest outbreaks and tree health. University of Illinois, Urbana-Champaign, Department of Entomology seminar series.
5. Frank, S.D. 2014. Can forests take the heat? Effects of warming on tree pests and health. Triangle Climate and Landscape Researchers' Seminar, NCSU Centennial Campus.
6. Frank, S.D. 2013. Can forests take the heat? Effects of warming on tree pests and health. University of Georgia, Department of Entomology Seminar Series.
7. Frank, S.D. 2013. Pests on plants for people. NCSU, Department of Entomology Seminar Series.
8. Meineke[†], E.K., Frank, S.D., and Dunn, R.R. 2013. Climate change and herbivorous pests that threaten forests: What we can learn from urban heat islands. Triangle Climate and Landscape Researchers' Seminar, NCSU Centennial Campus.
9. Frank, S.D. 2012. Hot in the City: Scale insects, parasitoids, and the future of warmer urban trees. Pennsylvania State University, Department of Entomology seminar series.

10. Frank, S.D. 2012. Hot in the City: Scale insects, parasitoids, and the future of warmer urban trees. The Ohio State University, Department of Entomology seminar series.
11. Frank, S.D. 2012. Hot in the City: Scale insects, parasitoids, and the future of warmer urban trees. University of North Carolina Greensboro, Biology Department seminar series.
12. Frank, S.D. 2011. Safari of your garden. Ecology and Evolution of Our Wild Lives Symposium, North Carolina Museum of Natural Sciences.
13. Dale, A.G. and Frank, S.D. 2014. Urban warming and pests combine to reduce street tree condition. Entomological Society of America, Portland, OR.
14. Youngsteadt, E., Savage, A.M., Dunn, R.R., and Frank, S.D. Urban ecosystems in the wake of a superstorm: Arthropod communities withstand extreme flooding in New York City. European Congress of Entomology, York, England.
15. Frank, S.D., Dale[†], A.G., Meineke[†], E.K., Youngsteadt, E.K. 2014. Urban and global warming increase scale insect fitness and abundance. European Congress of Entomology, York, England.
16. Youngsteadt, E., A. M. Savage, R. R. Dunn, and S. D. Frank. 2014. Urban ecosystems in the wake of a superstorm: Arthropod communities withstand extreme flooding in New York City. European Congress of Entomology, York, England.
17. Frank, S.D., Dale[†], A.G, Meineke[†], E.K. 2014. Managing scale insects on urban trees. Entomological Society of America, Southeast Branch, Greenville, SC.
18. Meineke[†], E.K., Frank, S.D., and Dunn, R.R. 2013. Urban warming affects herbivore abundance and natural enemy efficacy on street trees. Entomological Society of America, National Meeting, Austin, TX.
19. Meineke[†], E.K. and Frank, S.D. 2012. Hot in the city: Urban heat affects scale insect abundance and ecology. Entomological Society of America, National Meeting, Knoxville, TN.
20. Frank, S.D., Meineke[†], E.K., Dale[†], A.G., Youngsteadt[§], E., and Dunn, R.R. 2013. Hot in the city: effects of urban heat on the ecology and evolution of urban forest pests. International Symposium on Biological Control of Arthropods, Pucon, Chile.
21. Frank, S.D., Dale, A.G., Youngsteadt, E. 2015. Canary in the coalmine: Do urban areas predict pest outbreaks in a warming climate? 26th USDA Interagency Research Forum on Invasive Species, Annapolis, MD. (poster)
22. Meineke, E.K., Youngsteadt, E., Dunn, R.R., Frank, S.D. 2014. Urban warming leads to higher abundance of two key herbivores and reduces ecosystem services. Entomological Society of America, Portland, OR.
23. Hamblin, A., Frank, S.D. 2014. Sizzling cities: Native bee community composition and thermal tolerances related to urban heat. Entomological Society of America, Portland, OR.

24. Sconiers, W., Meineke, E.K., Youngsteadt, E., Dale†, A.G. and Frank, S.D. 2014. Urban outbreaks of herbivores: Determining the effects of nutrients and drought on herbivore abundance in urban forests. Entomological Society of America, Portland, OR.
25. Youngsteadt, E., Savage, A.M., Dunn, R.R., and Frank, S.D. 2014. Heat islands in the megalopolis: Effects of urban and regional climate on street-tree arthropods from Raleigh to Boston. Entomological Society of America, Portland, OR.
26. Appler†, R.H., Frank, S.D., and Tarpy, D. 2013. Immunocompetency and oxidative stress resistance of honey bee populations across the urbanization gradient. Entomological Society of America, National Meeting, Austin, TX.
27. Youngsteadt§, E., Savage, A., Dunn R.R., and Frank, S.D. 2013. Weathering the storm: Hurricane Sandy effects on New York City arthropods. Entomological Society of America, National Meeting, Austin, TX.
28. Dale†, A.G. and Frank, S.D. November 2013. Mechanisms affecting pest performance on urban red maple trees. Entomological Society of America, National Meeting, Austin, TX.
29. Dale†, A.G. and Frank, S.D. 2013. Temperature affects gloomy scale (Melanaspis Tenebricosa) abundance on urban trees. North Carolina State University, Graduate Student Research Symposium, Raleigh, NC.
30. Dale†, A.G. and Frank, S.D. 2012. Maple Spider Mites: Can they take the heat? North Carolina Entomological Society annual meeting. Raleigh, NC. Poster presentation.
31. Youngsteadt§, E., Frank, S.D., Sanders, N., and Dunn, R.R. 2012. Canary in the coalmine: Do urban areas predict pest outbreaks in a warming climate? Entomological Society of America, National Meeting, Knoxville, TN.
32. Dale†, A.G. and Frank, S.D. 2012. Temperature affects gloomy scale (Melanaspis tenebricosa) abundance on urban trees. Kanuga Ornamental Workshop, Hendersonville, NC.
33. Meineke†, E.K., Frank, S.D., Dunn, R.R., and Sexton, J.O. 2012. Scale insects, parasitoids, and the future of warmer urban trees. Ecological Society of America, National Meeting, Portland, OR.

Extension Presentations to Foresters, Urban Foresters, Arborists, and Landscapers

1. March 4, 2014. Can forests take the heat? Managing pests and ecosystem services on urban forests. Under the Big Top: Annual Virginia Urban Forest Council Workshop (keynote speaker).
2. January 30, 2014. Managing Pests and protecting pollinators. John Deere Landscapes University, Myrtle Beach, SC.
3. January 8, 2014. Identification and management of scale insect pests. Southside grounds maintenance conference, Danville Virginia.

4. August 23, 2013. Hot in the city: Heat causes pest outbreaks on urban trees. Farwest Show, Portland, Oregon.
5. August 15, 2014. Effects of urbanization on scale insect abundance and tree health. NC Urban Forest Council Annual Meeting, Raleigh, NC. A.G. Dale and S.D. Frank.
6. June 20, 2014. Managing pests and protecting pollinators. Landscape Color Field Day.
7. June 5, 2014. Managing pests in the landscape. Franklin, NC. Attendance 35.
8. February 18, 2014. Scales whiteflies, and other insects that suck. Sandhills Turf and Ornamental Conference, Carthage, NC.
9. February 11, 2014. Managing scale insects and emerald ash borer. Charlotte Landscape Seminar, Monroe, NC.
10. January 15, 2014. Urban heat increases herbivore abundance on street trees. Green and Growin' Trade Show, Greensboro, NC. Attendance 45.
11. December 5, 2013. Managing scale insects in the landscape. Landscape workshop, Burgaw, NC.
12. November 1, 2013. Hot in the City: Heat causes pest out-breaks on urban trees. NC Urban and Community Forest Council, Carolina Canopy Workshop, Greenville, NC.
13. January 22, 2013. Emerging and established pests of urban trees. Wilson, NC. Attendance 40.
14. January 22, 2013. Managing insect pests of urban trees. Grounds Maintenance Workshop, Winston-Salem, NC. Attendance 75.
15. January 16, 2013. Hot in the city: Research update on pest management in nurseries. Greensboro, NC. Attendance 55.
16. January 15, 2013. Hot in the city: Causes and management of pest outbreaks on urban trees. Greensboro, NC. Attendance 55.
17. December 6, 2012. Scouting and managing urban forest pests. Rutherford Landscape Workshop, Rutherfordton, NC. Attendance 70.
18. November 1, 2012. Scouting and managing urban forest pests. North Carolina Urban Forest Council, Wilmington, NC. Attendance 60. June 20, 2012.
19. May 16, 2012. Insects and other annoying critters. Landscape professional field day, J.C. Raulston Arboretum. Attendance 350.
20. March 20, 2012. Scouting and managing urban tree pests. Raleigh, NC. Attendance 11.
21. March 2, 2012. Scouting and Managing Pests of Urban Trees. Pitt Co. Landscape Conference.
22. January 18, 2012. Scouting and managing urban tree pests. Green and Growin' Trade Show, Greensboro, NC. Attendance 45.
23. August 18, 2011. Prepare for the invasion: New tree pests coming to the Southeast. NCNLA Summer Green Trade Show, Raleigh, NC. Attendance 15.
24. June 29, 2011. New landscape pests. Landscape color field day. J.C. Raulston Arboretum, Raleigh, NC. Attendance 125.