MODELING URBAN HOST TREE DISTRIBUTIONS FOR INVASIVE FOREST INSECTS USING A TWO-STEP APPROACH

Mark J. Ambrose, Frank H. Koch, Denys Yemshanov, and P. Eric Wiseman[1]

Abstract – Many alien insect species currently impacting forested ecosystems in North America first appeared in urban forests. Unfortunately, despite serving as critical gateways for the human-mediated spread of these and other forest pests, urban forests remain less well documented than their "natural" forest counterparts. While Forest Inventory and Analysis (FIA) data provide good information about the composition of natural forests, only a small percentage of the more than 26,000 communities in the US and Canada have completed any sort of urban forest inventory, and these inventories have commonly been restricted to street trees. We devised a two-step approach that utilizes the available local inventory data to comprehensively model urban host tree distributions at a regional scale. We illustrate the approach for three tree genera – ash (*Fraxinus*), maple (Acer), and oak (*Quercus*) – that are associated with high-profile insect pests. Available inventory data include 60 sample-based inventories of entire cities (i-Tree Eco inventories) and 475 street tree inventories. First, based on existing inventories, we use a suite of explanatory spatial variables to model the proportion of the total basal area (as a proxy for forest volume) occupied by each genus. Second, we apply a similar suite of spatial variables to estimate the total basal area of these communities. These estimates will be combined to estimate basal area of each genus in non-inventoried communities and to construct region-wide urban distribution maps for each genus. By merging these maps with similar data on natural forests (e.g., distribution maps developed from FIA plot data), we are able to provide a more complete host setting for spread modeling efforts. Urban FIA projects promise to provide information about the composition of urban forests, but it will be some time before most US urban areas have been inventoried intensely. This modeling approach provides a use for urban FIA data as they become available to better understand urban forests at larger spatial scales.

INTRODUCTION

Many alien insect species currently impacting forested ecosystems in North America first appeared in urban forests. Unfortunately, despite serving as critical gateways for the human-mediated spread of these and other forest pests, urban forests remain less well documented than their "natural" forest counterparts. Forest Inventory and Analysis (FIA) plot data are an excellent resource for estimating host species distributions, since they provide a nationwide, systematic, and fairly intensive sample. However, FIA data generally do not depict conditions in urban forests (with the exception of the limited amount of Urban FIA data that are just coming on-line). This results in a major data gap with respect to forest pests, in terms of both the early detection of new pests as well as the modeling of pest spread, including spread via human-mediated pathways (U.S. Government Accountability Office 2006).

[1] Research Assistant (MJA), Department of Forestry & Environmental Resources, NC State University, Forestry Sciences Laboratory, 3041 Cornwallis Rd., RTP, NC 27709; Research Ecologist (FHK), USDA Forest Service, Southern Research Station, Eastern Forest Environmental Threat Assessment Center, RTP, NC; Research Scientist (DY), Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON; Associate Professor (PEW), Department of Forest Resources and Environmental Conservation, Virginia Tech, Blacksburg, VA. MJA is the corresponding author: to contact, call (919) 549-4078 or email mambrose@fs.fed.us .

Many communities have some sort of independent urban inventory, but they are piecemeal and have a variety of formats and sample densities. This makes it challenging to apply such data for broad-scale analyses (such as a pest risk map). Our objective is to compile such available urban forest inventory data, and use them as basis for models to estimate presence of host trees of interest in non-sampled communities throughout study region (Eastern US). We focus on key host genera for three prominent invasive forest insect pests in Eastern US, maple (*Acer*), ash (*Fraxinus*), and oak (*Quercus*).

DATA AND METHODS

Data

We acquired urban forest inventory data from over 700 communities across the United States and Canada. Data are from two basic types of inventories: (1) sample-based whole-city (e.g., i-Tree ECO, formerly known as UFORE; Nowak and Crane 2000; Nowak et al. 2008) inventories; (2) street tree/public tree inventories. Of these datasets, the vast majority were from street/public tree inventories.

The street tree inventory data, usually lacked information needed to determine the absolute dominance (i.e., in terms of BA per hectare) of our genera of interest. Therefore, we used relative basal area (BA) as our measure of the importance of each genus in urban forests. For each inventory dataset we calculated the proportion of BA represented by each of the three genera.

Step 1: Modeling relative basal area

Our interest was in the overall urban forest tree population, but most of our data came from street/public tree inventories. So our first step was to model the relationship between street tree and whole-city populations using data from cities where both types of inventory had been conducted. We had data of both types from 41 cities across the US and Canada, but these cities were spatially imbalanced; clustered in certain states (MN, VA). To address this imbalance, we used geographically weighted regression (GWR) (ESRI 2012), where the dependent variable was relative BA for each genus from whole-city inventory and the independent variable was the relative BA from street tree inventory. In GWR, an individual regression runs for each observation, using an adaptive kernel to determine neighborhood for each model.

We then applied the GWR models to adjust the BA proportions in the 464 Eastern US cities having only street tree inventories and combined those data with the 60 cities that had whole-city inventories that did not require adjustment.

Next, we constructed models to estimate BA proportion for each host genus from the adjusted data set. We used boosted decision trees (Sherrod 2014) with a 20% validation (random) sample. Our explanatory variables included the following:

- Geographic: latitude, longitude, elevation
- Demographic: population (2010 Census)
- Climatic: annual extreme minimum temperature, summer maximum temperature, precipitation, growing degree days, last freeze, annual number of wet days, moisture index
- Land cover: proportion natural, agriculture, developed, forested; road density

Step 2: Modeling total urban forest basal area

Total urban forest BA per hectare estimates were available from i-Tree Eco output for 78 cities across continental US. Our aim was to relate total urban forest BA (all species) to canopy cover. Canopy cover estimates were derived from 2011 National Land Cover Database (NLCD). The canopy cover map product (30-m spatial resolution) was developed in cooperation with USFS.

We again used GWR, with an adaptive kernel to determine modeling neighborhood for each observation. The primary explanatory variable was the estimate of each city's total canopy cover; this measure combines canopy density measure with city's total land area. Population density served as an additional explanatory variable

RESULTS AND DISCUSION

Our models of relative BA fit rather well for all three genera. The model explained 0.67 of the variation in relative BA of maple. The fit was not quite as good for oak, explaining only 0.59 of the variation. For ash, we needed to remove to outlying cities (Minot and Grand Forks, ND) to achieve a good fit. With those cities dropped from the data set, our model explained about 0.67 of the variation (Fig. 1).

Initial results of modeling total BA from canopy cover are encouraging. We achieved a good fit overall (r^2= 0.79), but the BA of a few cities was significantly under-predicted (Fig. 2). We aim to refine this model. We plan to seek additional data to expand the set of cities used for this portion of the model. We also will explore using additional explanatory variables.

We intend to combine our model of relative BA for our genera of interest with our total BA model to estimate the total BA for each genus in each city. Then we will apply the combined model steps to estimate amount of oak, ash, maple in all populated places across Eastern US. Ultimately, we hope to extend the models to the Western US and Canada.

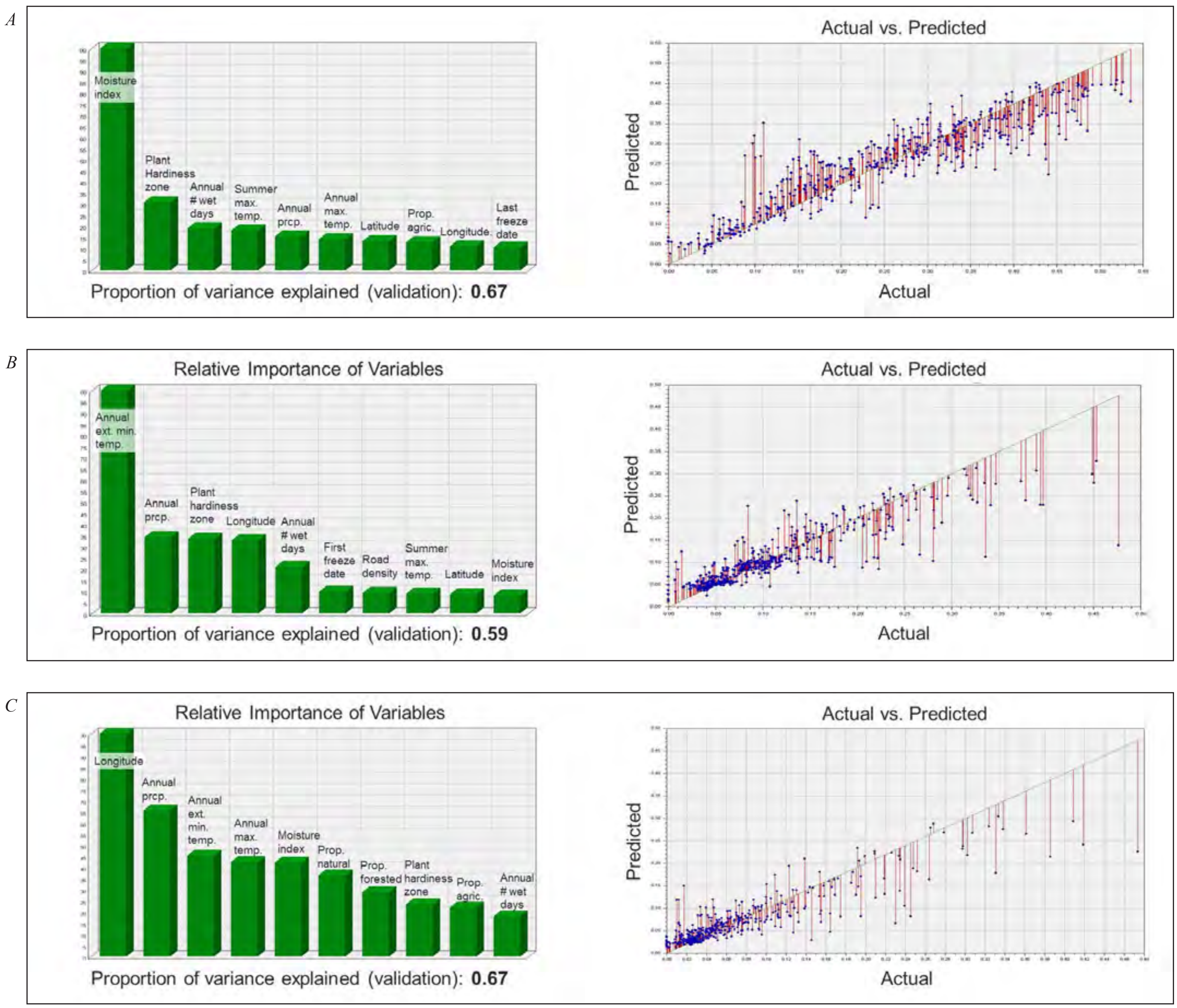

Figure 1—Results of boosted decision tree model for relative basal area of (a) maple, (b) oak, and (c) ash.

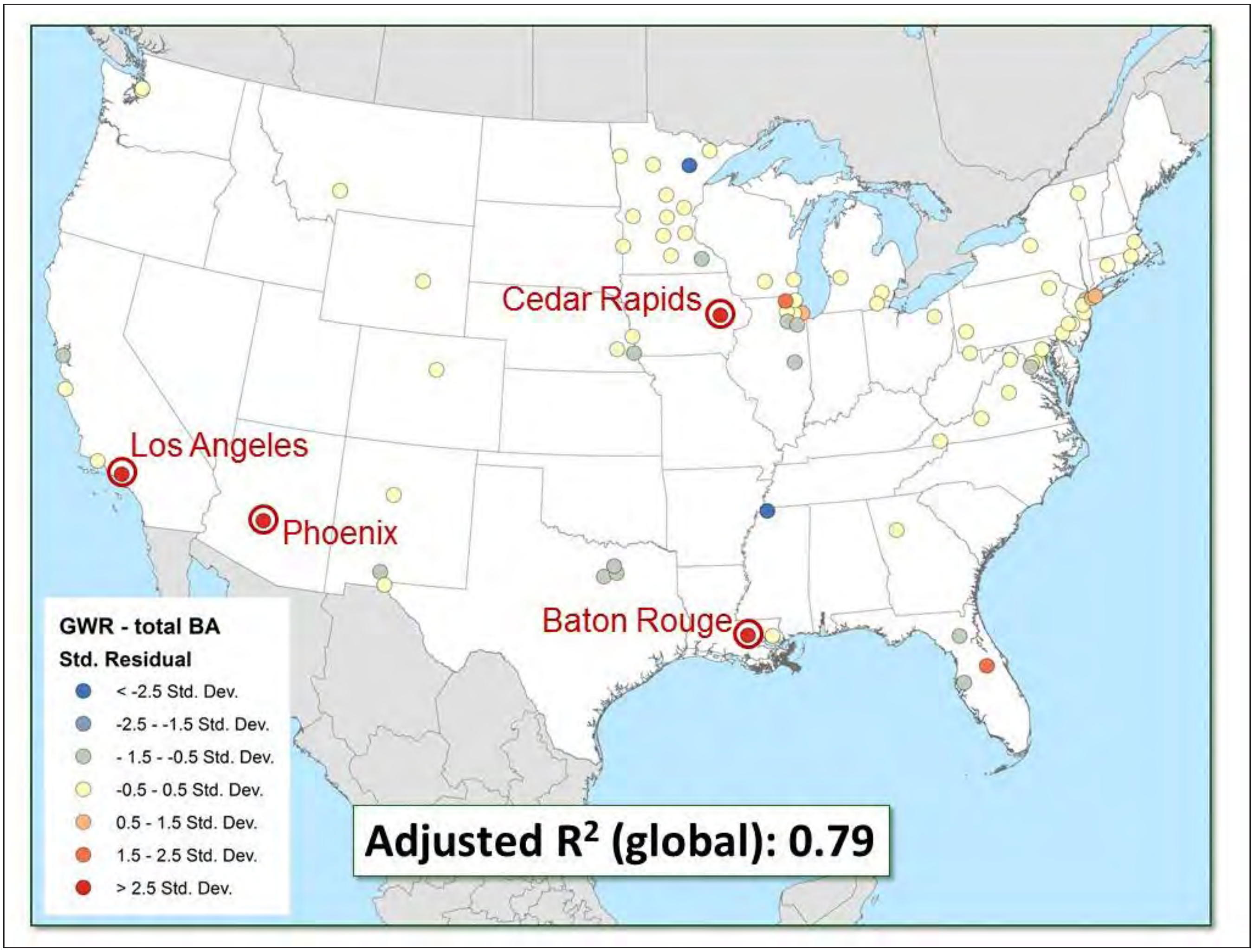

Figure 2—Results of geographically weighted regression of total urban forest basal area on city canopy cover. Cities where the model strongly under-predicts the basal area are circled in red.

By merging these maps with similar data on natural forests (e.g., distribution maps developed from Forest Inventory and Analysis plot data), we are able to provide a more complete host setting for spread modeling efforts. Urban FIA projects promise to provide information about the composition of urban forests, but it will be some time before most US urban areas have been inventoried intensely. This modeling approach provides a use for urban FIA data as they become available to better understand urban forests at larger spatial scales. It may be useful to consider FIA urban inventories as potential input to models such as these when determining where to implement future urban FIA i-Tree Eco inventories.

ACKNOWLEDGMENTS

Space does not allow us to name them all, but we are indebted to literally hundreds of municipal foresters, State urban forestry coordinators, foresters working in the US Forest Service Urban and Community Forestry Program, staffs of urban forestry-related NGOs, and university researchers who supplied us with data. Without their cooperation, this research would have been impossible. Special thanks go to Dave Nowak, Research Forester, US Forest Service, Northern Research Station and the other researchers in the Urban Forest Research Work Unit for their aid in obtaining key datasets and their valuable comments on this work.

LITERATURE CITED

ESRI. 2012. ArcGIS, version 10.1. ESRI, Redlands, CA.

Nowak, D.J. and D.E. Crane. 2000. The Urban Forest Effects (UFORE) Model: quantifying urban forest structure and functions. In: Hansen, M. and T. Burk (Eds.) Integrated Tools for Natural Resources Inventories in the 21st Century. Proc. of the IUFRO Conference. USDA Forest Service GTR NC-212. North Central Research Station, St. Paul, MN. pp. 714-720. http://www.treesearch.fs.fed.us/pubs/18420

Nowak, D.J., R.E. Hoehn, D.E. Crane, J.C. Stevens, J.T. Walton, and J. Bond. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboric. Urb. For. 34(6):347-358. http://www.treesearch.fs.fed.us/pubs/19526

Sherrod, P.H. 2014. DTREG Predictive Modeling Software. DTREG, Brentwood, TN. http://www.dtreg.com

U.S. Government Accountability Office. 2006. Invasive forest pests: lessons learned from three recent infestations may aid in managing future efforts. GAO-06-353. U.S. Government Accountability Office, Washington, DC. 118 p.