

2018 Annual Report

Forest Health Research and Education Center

Executive Summary

During this period the Forest Health Research and Education Center (FHC) has continued to evolve and work at growing the program through collaboration and grant writing, including the receiving of over \$1,000,000 in extramural funding. This year we have also developed several exciting new partnerships and collaborations including with the building White Oak Initiative, pulling together a diverse range of academic, government, and industry stakeholders to advance the sustainability and restoration of white oak resources.

Center and team leadership remains the same as in the previous year, with Dr. Jeff Stringer (UK, Forestry and Natural Resources, Chair) and Dr. Dana Nelson (SRS, Project Leader) serving as co-Directors and Drs. Bert Abbott (UK, FHC and Penn State, Schatz Center), Dr. Thomas Ochuodho (UK, FNR) and Dr. Ellen Crocker (UK, FNR) serving as Teams Leaders for the Biological and Social Sciences Research and Outreach and Education Teams, respectively. One important change is that Dr. Crocker was hired as a tenure-track faculty within FNR (official start date Feb. 1, 2019) and with responsibility for leading the FHC's Outreach and Education Team as one of her assignments. In addition, the FHC continues to host two full-time USDA Forest Service (USFS) scientists on UK's campus, Dr. Nelson, Research Geneticist, and Dr. Tyler Dreaden, Research Pathologist, as well as two research associates, Dr. Shenghua Fan and Dr. Laura Georgi and graduate students William Thomas, Rachel Landham, and Beth Kyre.

This report details some of the specific projects each team (i.e., Biological Sciences, Social Sciences, and Education & Outreach) has identified as priorities for their disciplines and areas of responsibility. In addition each team reports on their progress in terms of work published and presented and grants submitted and awarded. The Biological Sciences Team has made exciting progress, particularly towards the development of genome resources for chestnut and improved information on root rot and blight resistance genes. Collaborations between all three teams continue to develop which include understanding threats to forest health, developing tools and programs for citizen science and implementing collaborative tree breeding with forest health objectives. These efforts culminated this year in the funding and recruitment of a white oak geneticist and tree breeder. Dr. Laura DeWald who will join the FHC in this capacity full-time in May 2019. We celebrate this year's accomplishments and look forward to the coming years' efforts in partnership building and grantsmanship to advance our research objectives on various continuing and new emerging projects, and our continued engagement in a broad interest network of forest health collaborators.

Funding

Funding received (6 grants totaling \$1,062,734, bold names indicate FHC-affiliated):

- **Crocker E, Staton M, and J Stringer.** HealthyWoods: A New Mobile App Tool to Guide Landowners in Forest Health Assessment. USDA RREA NFF, \$100,000, Oct 2018.
- Agouridis C, **Crocker E**, Odom S, and R Hirsh. “Expanding Your Horizons- a STEM Workshop for Middle School Girls” NSF EPSCoR, \$10,000, Sept. 2018.
- **Crocker E, Abbott, AG, and Nelson, CD.** Supporting The 2018 Conference "Tree Resistance To Insects And Diseases: Putting Promise Into Practice.” USDA AFRI Foundational Program Area, Pests and Beneficial Species in Agricultural Production Systems, \$35,000, July 2018.
- **Crocker E, Arthur M, Rieske-Kinney L, Nelson CD, Lhotka J, and J Christian.** Development of an Undergraduate Certificate in Urban and Community Forestry. USDA HEC, \$149,734, March 2018.
- **Crocker, E, Nielson, A., Hain, F., Nelson, CD, et al.** USFS LSR citizen science, working with NC Forest Service and KDF on hemlock/HWA and ash/EAB. Proposal submitted and awarded (\$143,000 + \$150,000 match).
- DeBolt, S., **Nelson, CD, Abbott, AG.** UK—KSI White Oak Initiative, White oak genome project proposal (submitted; tentatively funded, \$625,000).

Continued funding from last year.

- D Main, Jung, Wegrzn J, **Staton M**, Ficklen S, **Abbott AG, and CD Nelson.** ABR-PG Standards and CyberInfrastructure That Enable "Big-Data" Driven Discovery For Tree Crop Research. NSF-PGRP, \$3,400,000, continued and extended to June 30, 2020
- **A. Abbott, Co-Pi: Z. Liu, C. Dardick, M. Staton, C.D. Nelson.** Abiotic Stress Response And Adaptive Phenology In Fruit Trees. USDA-AFRI, \$425,220 01/01/2016-12/31/2019, continued and extended to Dec. 14, 2019.

Funding being sought or pending (2 grants totaling \$10,017,058):

- Lhotka JM, **Abbott AG**, Coggeshall M, Contreras M, Day D, Debolt S, **Ochudho TO**, Carlson J, **Nelson CD**, Stambaugh M, Staton M, Stringer J, **Crocker E**, Yang J, Mo Z, Brandeis C, Aguilar F. “Sustaining Resilient Forest Industries and Prosperous Rural Communities through Advanced Forestry Systems for the Oak Resource”. USDA-NIFA-AFRI Sustainable Agricultural Systems (SA) Program. Coordinated Agricultural Project \$10,000,000, 2018.
- **Crocker E and T Dreaden.** Identification of endophytes of “lingering” ash for biological control of emerald ash borer. Tree Fund John Z. Duling Grant. \$17,058.

Unsuccessful proposals (14 grants totaling \$7,491,459):

- Contreras M, Liu K, **Ochuodho TO**, Sena K, and C Niman. 2018. “Evaluating the feasibility of establishing biomass combined heat and power systems in economically deprived areas of eastern Kentucky”. University of Kentucky, Agricultural Experiment Station. Igniting Research Collaboration (IRC). \$33,000. Co-Principal Investigator.
- **Ochuodho TO**, and J Yang. 2018. “Integrated Spatio-Economic Decision Support System for Evaluating Ecosystem Services Supply and Use” USDA-NIFA-AFRI Foundational and Applied Science Program 2018. Environmental and Natural Resource Economics Program Area Priority, \$500,000.
- **Ochuodho TO**, and M Contreras. 2018. “Integrated Bioenergy Production Logistics and Economics Decision Support System”. USDA-NIFA-AFRI Foundational and Applied Science Program 2018. Bioenergy and Biobased Product Feedstock Logistics Program Area Priority (\$719,590).
- Contreras M, **Ochuodho TO**, Lhotka JM, and C Niman. 2018. “Developing wood bioenergy opportunities in the central Appalachian region: understanding economic and spatial constraints on use of timber industry byproducts and low-quality standing timber for bioenergy”. U.S. Forest Service Wood Innovations (\$267,386).
- Rignall K, **Ochuodho TO**, Shade L, and J Yang. 2018. “Coupled Systems in Changing Energy Landscapes: Assessing How Land Ownership Mediates Natural and Human Processes in Central Appalachia” to The Dynamics of Coupled Natural and Human Systems (CNH) Program of the NSF (\$1,569,705).
- **Crocker E**. Citizen Science Tracking of Invasive Threats Through a Mobile App. KY Farm Bill, **\$83,972**.
- Dvorak T, **Crocker E**, and R Hirsch. Sparking STEM: Integrating Biotechnology into Informal Youth Education to Train Tomorrow’s Workforce. NSF Advancing Informal Science Learning. **\$601,928**.
- Rignall K, **Ochuodho T**, Shade L, and J Yang. “Coupled Systems in Changing Energy Landscapes: Assessing How Land Ownership Mediates Natural and Human Processes in Central Appalachia” NSF Dynamics of Coupled Natural and Human Systems (CNH) Program, **\$1,569,705**.
- **Abbott AG**, **Dreaden TJ**, Merkle S, **Nelson CD**, **Staton M**. Genetic foundations of resistance to *P. cinnamomi* in Chinese chestnut NSF Plant Biotic Interactions, **\$1,172,173**.
- **Nelson CD**, **Crocker E**, **Stringer J**, and **AG Abbott**. University of Kentucky, Office of the Vice President. Forest Health Research and Education Center. **\$480,000**.
- **Crocker E**, **Stringer J**, Barrett S, Benton E, Bobby L, Heaton C, Hubbard B, Khanal P, Jackson B, and H Stelzer. USDA AFRI ELI REEU. Development of a National Forestry and Natural Resources Extension Fellowship. **\$494,000**.

- **Abbott, AG, Nelson CD**, et al. NSF EAGER, Early Concept Grants for Exploratory Research (EAGER), joint USA (NSF) and UK call for proposals, genetics of EAB resistance in ash (proposal submitted July 2018; not funded)
- **Abbott, AG, Zhebentyayeva, T, Deaden T, Nelson, CD**, et al. NSF-Biotic Interactions Program. Genetic foundations of resistance to *P. cinnamomi* in Chinese chestnut, (submitted; not funded)

Key Partnership Development

1. Collaborating on Forest.Health (www.Forest.Health.org) and Institute of Forest Tree Breeding proposal development
 - a. Provide information for Southern Group of State Foresters meeting (June 2018)
 - b. Presented new developments in Tree Resistance Workshop talk (August 2018)
 - c. Invited to USFS WO-sponsored meeting in Placerville, CA (9/10-14/18), participated by phone and Skype. Assisted with report development.
2. Working on leadership team to develop Forest.Health project
 - a. First meeting held 11/28-29/18 in DC
3. White oak genetics program with USFS LSR and UK-KSI funding
 - a. Recruited and hired Laura DeWald as white oak geneticist and tree breeder
 - b. White oak germplasm collection initiated using TreeSnap and KDF collaboration
4. RNAi approaches for insect control with Lynne Rieske-Kinney (UK-- Entomology)
 - a. Graduate student committee (Beth Kyre, studying RNAi in southern pine beetle)
 - b. Developed partnership with University of Georgia on transforming ash with RNAi genes for EAB control (research contract initiated)

New personnel hires and collaborators

- New Social Sciences Team advisory board members: Dr. Sayeed Mehmood (Ohio State University), Dr. John Munsell (Virginia Tech), and Dr. Rajan Parajuli (North Carolina State University)
- Hired faculty position created in UK Department of Forestry and Natural Resources, Forest Health Extension that will lead FHC outreach efforts long term. Candidate selected (Ellen Crocker) starting Feb 1, 2019.
- Laura Georgi, new collaborator on QTL mapping in chestnut
- Laura DeWald, new research associate leading development of a white oak genetics and improvement program at the University of Kentucky

Student research updates

- Undergraduate research interns working with Forest Health Center summer of 2018.
 - Hannah Hallowell and Sarah Hays working on mix of outreach and research.
- William Thomas, PhD student in UK Department of Sociology, research project on woodland owner attitudes to woodland management.
- Rachel Landham, Master's student in UK Department of Forestry and Natural Resources, thesis research project on white oak genetics, resuming work.
- Ellen Crocker, postdoctoral scholar, will assume new role Feb 1, 2019 as Forest Health Extension Assistant Professor and continue leading Education and Outreach team in this role.
- Jiali Yu, graduate student in Meg Staton's lab University of Tennessee.
- Beth Kyre, graduate student in Lynne Rieske- Kinney lab doing RNAi work in southern pine beetle.

Biological Sciences Team Summary

The biological sciences team continues to make significant progress on key research projects while initiating other in 2018.

- 1) We have submitted a manuscript (tentatively accepted with revision), on characterizing the genetic nature of resistance to *P. cinnamomi* in Chinese chestnut X American chestnut hybrid families.
- 2) We have continued to work on understanding the genetic basis for resistance to *C. parasitica* in Chinese chestnut through further high density mapping of the trait in expanded and new backcross and F2 Chinese-American hybrid progenies.
- 3) We have completed our objectives for our funded USDA- project on understanding the control of dormancy and response to abiotic stress in fruit trees and are leveraging this information to addressing the challenges to sustaining our forest trees brought on by rapid climate change. We have one manuscript (in revision with tentative acceptance) focused on metabolomics of bud dormancy in apricot. We have several manuscripts in preparation on RNAseq analyses of apricot and peach buds throughout the winter dormancy period. We are initiating transgenic testing of candidate genes for control of winter dormancy with our collaborators at the USDA-ARS, Appalachian Fruit Research Station in Kearneysville WV.
- 4) The Lynn Riske-Kinney laboratory has continued to advance her research on RNAi induced resistance to invasive beetle pathogens such as emerald ash borer and we have initiated a transgenic study with Dr. Scott Merkle's group to potentially produce trees resistant to EAB.
- 5) To study the genetic structure of *Torreya taxifolia*, an endangered conifer to assist in development of species preservation strategies, we have initiated two projects: 1) We are developing a screening method to detect the canker pathogen on seed and

- seedlings to make sure we are not spreading the pathogen to currently clean ex situ collections of the rare conifer. We have a PCR based assay working and are now working with the Atlanta Botanical Garden to develop the seed screening assay; and
- 2) We are developing an SSR based fingerprinting method to identify individual trees in both in situ and ex situ collections. We will also use the SSR panel to answer reproductive and population genetic questions.
 - 6) We are contributing to the final Chinese chestnut genome manuscript cooperating with J. Carlson's group at Penn State. We have integrated our new high-density molecular marker maps of Chinese chestnut and Chinese X American chestnut hybrid families to construct pseudochromosomes and assisted in identifying candidate genes for important disease resistance and phenology traits. The final manuscript is currently being drafted for submission this spring.
 - 7) Finally, we have continued to develop a white oak (*Q. alba*) genetics/genomics program as a first step in sustaining and improving this valued resource as part of the multiregional and institutional White Oak Initiative, we have received funding for cooperative effort with the Kentucky Spirits Institute to sequence the white oak genome.

Detailed descriptions of the individual project accomplishments are provided below.

1. Phytophthora research:

The following is a cooperative project with Dr. Tatyana Zhebentyayeva (Penn State University), funded through the FHC with a grant from the Foundation of the Carolinas.

Response to Phytophthora cinnamomi in Chestnut Roots: An Integrated QTL mapping, Transcriptome and Metabolome Approach

Due to availability of resistant Asian and susceptible American and European chestnut species, *Castanea* is ideally suited for studying plant-*Phytophthora cinnamomi* (Pc) interactions. We employed a genetic approach to map resistance to Pc in interspecific crosses using resistant Chinese chestnut, *Castanea mollissima* ('Mahogany' and 'Nanking' resistance donors), and susceptible American chestnut, *Castanea dentata* (multiple parents). Five cohorts for three hybrid crosses (BC1 and BC3) phenotyped for severity of root symptoms in 2013-2014 were genotyped by sequencing and used for linkage map construction /QTL mapping. Altogether 17 QTLs were detected with eight parental maps. Of these, a major QTL signal in the middle of LG_E (qPcE.2) was associated with resistance to Pc in all crosses. Using markers anchored to the *C. mollissima* genome v1.0 assembly, we designed a set of 47 SSR markers within the three LG_E QTL intervals most associated with resistance to Pc. These markers are available for testing their predictive power in breeding material by TACF.

We initiated a functional genomics study for candidate gene discovery within QTL intervals and analyzed gene expression and metabolic profiles in chestnut roots interacting with *Pc* zoospores. In collaboration with plant pathology lab (Dr. S.N. Jeffers, Clemson University) we developed an inoculation procedure with *P. cinnamomi* zoospores in liquid media compatible with frequent sampling roots of infected plants, i.e., with their minimal mechanical damage. In a pilot experiment, we challenged 1-year old NK5 progeny (Nanking-derived F2 cross) with *Pc* and harvested root tissue at three time-points (2, 4 and 8 days) post inoculation. Non-inoculated plants were used as controls along with inoculated Chinese and American chestnut seedlings. Plants were monitored for progression of root rot symptoms and the three most resistant and three most susceptible plants were chosen for RNAseq analysis and metabolite profiling. In total 24 RNAseq datasets were generated for RNA expression and metabolic pathway analyses for narrowing down a list of candidate genes within QTL intervals. Nontargeted metabolite analysis of chestnut roots revealed that hydrolysable tannins, a complex group of complex polyphenols, represent 20% of compounds detected in chestnut roots (626 unique compounds in total). So, activation of the phenylpropanoid pathway may reflect the main mechanism of defense in the chestnut-*Pc* host-pathogen system.

Additionally, these high density hybrid family maps have been employed for finalizing the pseudochromosome assemblies for the Chinese chestnut whole genome sequence.

Published manuscripts:

- **Zhebentyayeva TN**, Sisco PH, Georgi LL, Jeffers SN, Perkins M.T., James JB, Hebard FV, Saski C, **Nelson CD**, **Abbott AG** (2019) Dissecting resistance to *Phytophthora cinnamomi* Rand. in interspecific chestnut populations using high-throughput genotyping and QTL mapping. *Phytopathology* (submitted revision in review, PHYTO-11-18-0425-R)

Presentations:

- **Zhebentyayeva T**, Gitto AJ, Jeffers SN, Sisco PH, Perkins MT, Craddock JH, Saski C, Westbrook JW, Hebard FV, **Georgi LL**, James JB, **Staton M**, **Nelson CD**, and **AG Abbott**. Genetic mapping and functional genomics analyses of the resistance/susceptible response in chestnut seedlings to *Phytophthora cinnamomi* infection. The 6th International Workshop on the Genetics of Tree-Parasite Interactions: Tree Resistance to Insects and Diseases: Putting Promise into Practice, International Union of Forest Research Organizations (IUFRO) - August 5, 2018 - August 10, 2018
- **Zhebentyayeva T**, Gitto AJ, Jeffers SN, Sisco PH, Perkins MT, Craddock JH, Saski C, Westbrook JW, Hebard FV, **Georgi LL**, James JB, **Staton M**, **Nelson CD**, and **AG Abbott**. Mapping the QTLs for *Phytophthora* resistance. The 36th annual meeting of NE-1333 chestnut Multistate Research Project, USDA/The Schatz Center for Tree Molecular Genetics, September 6, 2018 - September 9, 2018.

- **Zhebentyayeva TN**, Noorai RE, Gitto AJ, Jeffers SN, Sisco PH, Perkins MT, Craddock JH, Saski CA, Carlson JE, **Nelson CD**, and **AG Abbott**. Response. Functional genomics analyses of the resistance/susceptible response in chestnut seedlings to *Phytophthora cinnamomi* infection 2018 TACF Annual Meeting, TACF. October 26, 2018 - October 27, 2018.

2. Chestnut genetic mapping and QTL analyses of resistance to chestnut blight, *Cryphonectria parasitica*

Refined the Chinese chestnut reference genetic map

The reference map was constructed with two F1 crosses derived from three Chinese chestnut cultivars (Mahogany × Nanking and Vanuxem × Nanking) with additional SNP data genotyped with the Infinium array. The new map contains 1319 SSR and SNP markers with substantially improved coverage and density. A reciprocal translocation between linkage groups H and L in Chinese chestnut cultivar Vanuxem was also verified. The new reference map is served as the backbone for Chinese chestnut genome assembly.

Mapped QTLs for blight disease resistance and other biological traits

We have integrated the genotypic and phenotypic data of 3 backcross and 1 F2 families and performed a GWAS analysis for *C. parasitica* resistance and other traits segregating in these families. Each backcross or F2 family is either too small or has too complex a composition and pedigree for conventional mapping approaches. The detected QTL for *C. parasitica* resistance in linkage group B using the GWAS approach validated other previous mapping project results. Genetic loci controlling several other traits including male sterility, leaf hair, and leaf early emergence were also discovered.

Manuscript in preparation:

- **Shenghua F, Georgi L**, Islam-Faridi, N., **Abbott, AG, Nelson, CD**. The Chinese chestnut reference genetic map and translocation.
- **Shenghua F, Georgi L**, Hebard, FV, **Zhebentyayeva, T, Abbott, AG, Nelson, CD**. GWAS analysis detects blight resistant genes in chestnut using complex breeding materials

3. Abiotic Stress Project

We have essentially completed objectives one and two and made significant progress on objective three of our USDA-AFRI funded project entitled: Abiotic Stress and Adaptive Phenology in Fruit Trees. In this past year we have accomplished the following on each objective:

Objective 1: Using functional genomics approaches characterize genotypic effects on the phenylpropanoid gene network transcriptome during endodormancy and the EET.

We completed the RNAseq analyses of floral buds from early and late blooming apricot accessions and a manuscript is in preparation showing specific gene networks whose activities are correlated with different bud dormancy stages and that characterize the endodormant and ecodormant transition. From this work we hypothesize that the transition from the endodormant stage to the ecodormant stage is characterized by completion of floral development particularly pollen development. Associated with this transition are changes in hormonal gene network activities and networks involved in epigenetic responses. Currently, we are completing a similar analyses for the floral buds of peach siblings segregating for the high or low chilling requirement trait. Comparative analyses of the RNAseq datasets of peach and apricot floral buds throughout the dormancy period should reveal the common networks characterizing the physiological stages of endo and ecodormancy and potentially reveal key specific genes that show significant differences in expression between low chill/early bloom trees and high chill/late blooming trees. These would be or currently are targets for our objective 3 transformation analyses.

Objective 2: Examine the genotypic effects on the concentration of specific phenylpropanoid intermediates and the timing of resumption of growth post-dormancy. Completed in the previous year.

Objective 3: Employ transgenic systems to characterize the phenotypes of expression perturbations of specific pathway genes potentially implicated as control points for the EET.

- *Identification of candidate genes by genomic and metabolome studies.* Our genomic studies confirmed those of others that four of the six DORMANCY-ASSOCIATED MADS-BOX (DAM) genes are down-regulated by chilling, and this regulation is closely associated with conspicuous change of DNA methylation, histone modification, small RNAs (sRNAs) and noncoding RNAs (ncRNA). In parallel metabolome analysis coupled with transcriptome analysis, our team showed that phenylpropanoid production in dormant floral buds and subsequent growing buds is differentially regulated by chilling and developmental programming. Genes such as TRANSPARENT TESTA (TTRs) that control synthesis of various phenylpropanoids showed differential expression profiles between early and late blooming apricots and low or high chill requirement peach siblings implicating phenylpropanoid intermediates and their synthesis genes may play an important role in the dormancy-related processing and bloom date in peach and other trees. Accordingly, we choose DAMs and TTR genes for the functional analysis in transgenic plants.
- *Verification of the chosen genes in transgenic plum through RNAi silencing approach.* To validate the gene function, we took an RNAi approach to silence the DAMs and TTRs in plum that is closely related to peach because of the available transformation system. Specifically, we isolated the orthologous chosen gene fragments ranging 500 to 800 bp from plum, cloned into pCR™8/GW/TOPO, an entry vector for the Gateway cloning, confirmed them by sequencing, and introduced into pHELLSGATE8, a high-throughput binary Gateway® destination vector, to create an inverted repeat that is directly

transcribed by a strong, constitutive CaMV35S promoter. To date, we have successfully made RNAi constructs in the pHellsgate 8 background and plant transformation is in progress.

To extend the results from last years transgenic studies and further investigate candidate genes we are developing a new woody plant transformation platform for both RNAi silencing and ecotopical expression specifically in dormant flower buds. Although pHellsgate 8 provides an ideal tool for RNAi silencing, it still suffers a few drawbacks that seriously hamper the accurate assessment of the chosen gene's function in flowers. Firstly, the CaMV35S promoter is of viral origin and is primarily expressed in vegetative tissue with very weak expression in floral organs so that it is not the best promoter to interrogate the function of the chosen genes by either silencing or ecotopic expression. Secondly, the CaMV35S promoter-driven DAMs that code for transcription repressor factors, could potentially inhibit transformed cell growth, and reduce the transformation efficiency partially or completely. Hence, it is necessary to search or develop a flower-specific promoter from woody plants to replace the CaMV35S promoter in the pHellsgate 8 vector. This promoter must be expressed in female floral organs and throughout the entire floral developmental programming because much of this program runs during the dormancy period. In herbaceous plants, AGAMOUS (AG) regulates male and female floral organ identity and is also specifically expressed in these floral tissues. Genetic and molecular analyses revealed that its enhancer located in the second intron (AGE) primarily controls the floral organ-specific expression as supported by our early studies that the isolated AGEs from Arabidopsis, tobacco and petunia confer, when provided with a minimal promoter sequence (AGEp), very similar flower-specific expression in transgenic plants. Thus, AGEp is highly desirable for our transgenic studies in plum. To demonstrate that apple and plum homologous AGEs also confer a similar flower-specific expression, we isolated them, fused them with a minimal CaMV35S promoter sequence (~ 60 bp) and tested their ability to drive GUS, a marker gene widely used for promoter analysis, in transgenic tobacco. Our results showed that the woody plant-derived AGEs (WAGEp) are able to direct GUS specific expression in the stamen and carpel but not in vegetative tissues, confirming the conservation of the AGE's tissue specificity across a wide spectrum of plants. Accordingly, we replaced the CaMV35S promoter with confirmed woody WAGEp in Phellsgate8. We also introduced additional unique restriction sites in the vector to render it available for both RNAi and ecotopic expression analyses. Currently, we are in the process of cloning the chosen gene fragments and cDNAs into the new transformation vectors to specifically silence and overexpress the chosen genes. Once all constructs will be made, we will start plum transformation immediately.

Abstracts presented:

- **Yu J, Conrad A, Decroocq V, Zhebentyayeva T, Dardick C, Liu Z, Abbott A, and M Staton.** Transcriptomic profiling of endodormancy to ecodormancy transition in apricot (*P. armeniaca*). The Ninth International Rosaceae Genomics Conference in Nanjing China, June 26-30, 2018,
- **Conrad A.** Genomic analysis of the endodormancy-ecodormancy transition (EET) in trees. The 2018 Plant and Animal Genome Meeting, San Diego, Jan. 13-17, 2018,

Forestry Workshop.

Manuscripts submitted:

- **Conrad AO, Yu J, Staton ME**, Audergon J-M, Roch G, Decroocq V, Knagge K, Chen H, **Zhebentyayeva T**, Liu Z, Dardick C, **Nelson CD, and Abbott AG**. Association of the phenylpropanoid pathway with dormancy and adaptive trait variation in apricot (*Prunus armeniaca*). *Tree Physiology*. *In Revision*.

In addition to the work above, we have also carried out two other analyses: 1) a study focused on the genetic underpinnings of dormancy control in fruiting trees; and 2) a study to identify potential Plum Pox Potyvirus (PPV) resistance genes in apricot.

Apricot GWAS for dormancy/budbreak

Completed a GWAS analysis using Nextgen sequenced 119 apricot germplasm lines with 15 years of flowering time phenotypic data. We detected QTLs in linkage group 1, 2, 3, 4, 5, mainly in LG2 and 5. From this analysis we discovered that various combinations of QTL (genes) were triggered to regulate flowering time by different winter temperature regimes. Currently, transcriptome profiles of early/late flowering apricot cultivars during dormancy were integrated with these GWAS results to finalize a list of candidate genes/networks regulating apricot flowering time.

Manuscript in preparation:

- **Shenghua F**, Jaromczyk J, **Nelson CD, and Abbott, AG**. GWAS detects various QTL combinations regulating flowering time in different winter temperature regimes.

Apricot bulk sequenced GWAS for PPV resistance

We performed a genome wide bulk segregant analysis using two Nextgen sequenced bulks, each composed of 12 F1 siblings derived from the cross of two apricot cultivars with high (cv. Harlayne) and low (cv. Marlen) PPV resistance. We identified 121 candidate SNPs with larger than 70% allele frequency difference. Particularly, a SNP 1244 bp downstream of EF1a like gene showed 100% allele frequency difference in two bulks. We are further characterizing the potential functions in PPV resistance of these SNPs.

4. Biotechnological approaches to disease and pest resistance in forest trees.

Dr. Lynne Riske-Kinney's lab is evaluating the use of gene silencing as a means of suppressing forest pests. Focusing on the non-native emerald ash borer, *Agrilus planipennis*, and the endemic southern pine beetle, *Dendroctonus frontalis*, they have shown that RNA interference (RNAi) can silence genes and cause rapid and extensive beetle mortality. We are now evaluating additional genes that, when silenced, could cause beetle mortality, reduce fecundity, or disrupt chemical communication. We are also evaluating RNAi for its efficacy in related conspecifics, including the goldspotted oak borer, *A. auroguttatus*, and the mountain pine beetle, *D. ponderosae*. Additionally, we're evaluating methods of delivery and assessing potential non-target effects. Finally, developmental asynchrony between EAB and its classical biocontrol agents complicates implementation of an effective biological control program; we are assessing some of these issues with the goal of refining biological control for EAB in the southeast region.

The FHC biological sciences research team is also developing strategies to produce transgenic ash trees resistant to EAB. Employing the RNAi constructs in development in the Rieske laboratory with transgenic pipelines in development in Dr. Scott Merkle's group at UGA, we hope to deliver small RNAs, demonstrated to kill the larval forms in vitro, directly to the pest through its feeding on living plants. Through a subcontract from the FHC to Dr. Merkle's group, transgenic ash trees are in development and the technology is projected to be available for gene delivery of FHC engineered constructs by the end of this year.

Publications:

- **Rodrigues TB**, JJ Duan, SR Palli, **LK Rieske**. 2018. Identification of highly effective target genes for RNAi-mediated control of emerald ash borer, *A. planipennis*. *Scientific Reports* 8, 5020. DOI:10.1038/s41598-018-23216-6.
- Olson DG, **LK Rieske**. 2018. Host range expansion may provide enemy free space for the highly invasive emerald ash borer. *Biological Invasions* 20, 1-11. DOI:10.1007/s10530-018-1853-6.

5. Forest tree preservation research

Under the direction of Dr. Tyler Dreaden, two projects were initiated this year focused on developing tools to assist in preservation of the endangered *Torreya taxifolia*, or Florida nutmeg tree. The first is to develop a screening method to detect the canker pathogen on seed and seedlings to make sure we are not spreading the pathogen to currently clean ex situ collections of the rare conifer. He has developed a PCR based assay for the pathogen detection and is now working with the Atlanta Botanical Garden to develop the seed-screening assay. The second project is developing an SSR based fingerprinting method so we can identify individual trees in both in situ and ex situ collections. We will also use the SSR panel to answer reproductive and population genetic questions.

Other projects include surveying for *P. cinnamomi* distribution in the Kentucky watershed, continuing genetic studies of *Raffaelea lauricola*, the Laurel wilt pathogen, and more recently, endophyte studies of lingering ash trees post emerald ash borer infestations.

Publications:

- **Dreaden TJ**, Hughes MA, Ploetz RC, Black A, and JA Smith. 2018. Genetic Analyses of the Laurel Wilt Pathogen, *Raffaelea lauricola*, in Asia Provide Clues on the Source of the Clone that is Responsible for the Current USA Epidemic. *Forests*. 10, 37; doi:10.3390/f10010037.
- Kobziar LN, Pingree MRA, Larson H, **Dreaden TJ**, Green S, and JA Smith. 2018. Pyroaerobiology: the aerosolization and transport of viable microbial life by wildland fire. *Ecosphere*. 9(11):e02507. 10.1002/ecs2.2507.
- **Sena KL**, **Dreaden TJ**, **Crocker E**, and CD Barton. 2018. Detection of *Phytophthora cinnamomi* in forest soils by PCR on DNA extracted from leaf disc baits. *Plant Health Progress* 19:193-200. DOI:10.1094/PHP-01-18-0004-RS.

- **Sena KL**, Yeager KM, **Dreaden TJ**, and CD Barton. 2018. *Phytophthora cinnamomi* Colonized Reclaimed Surface Mined Sites in Eastern Kentucky: Implications for the Restoration of Susceptible Species. *Forests*. 19:193-200. doi:10.3390/f9040203.

Presentations:

- **Dreaden TJ**, MA Hughes, RC Ploetz, A Black, and JA Smith. Genetic diversity in the laurel wilt pathogen, *Raffaelea lauricola*, and the consequences for resistance breeding. IUFRO 6th International Workshop on the Genetics of Tree-Parasite Interactions: Tree Resistance to Insects and Diseases: Putting Promise into Practice. Mt. Sterling, OH. August 5-10, 2018.
- **Dreaden TJ**. . Developing Resistance to Laurel Wilt Disease in Redbay. Forests of the Future: Bring Back Iconic American Trees! Urban Forest Seminar Series. Lexington, KY. July 11, 2018.

6. The Chinese chestnut genome project

We continue to be major contributors to completion of the Chinese chestnut whole genome sequencing project. Through our cooperation with Dr. John Carlson's group at Pennsylvania State University and that of Dr. Margaret Staton at the University of Tennessee, the Chinese chestnut genome is coming to completion. We have utilized our extensive chestnut mapping resources to assist in the development the Chinese chestnut (Cc) pseudochromosomes that we have leveraged for extensive studies linking QTL mapping results to candidate genes controlling: 1) resistance to the chestnut blight fungus, *C. parasitica* and resistance to the oomycete pathogen *P. cinnamomi*; and 2) phenological traits, such as bud emergence date. This work will underpin the science reported in the final genome manuscript that we expect to submit this spring.

Presentations:

- Carlson JE, **Staton ME**, Addo-Quaye C, Cannon N, **Fan S**, **Nelson CD**, Henry N, Yu J, Huff M, **Zhebentyayeva T**, **Conrad A**, Ficklin S, Saski C, Mandal M, Islam-Faridi N, Zembower N, Drautz D, Schuster SC, Swale T, Sun Y, Westbrook J, Holliday J, **Abbott AG**, and FV Hebard. 2018. The Chinese Chestnut Genome V2.0, The Annual Meeting of the American Chestnut Foundation, Huntsville, Alabama, October 25-27, 2018.
- Carlson JE, **Staton ME**, Addo-Quaye C, Cannon N, **Fan S**, **Nelson CD**, Henry N, Yu J, Huff M, **Zhebentyayeva T**, **Conrad A**, Ficklin S, Saski C, Mandal M, Islam-Faridi N, Zembower N, Drautz D, Schuster SC, Swale T, Sun Y, Westbrook J, Holliday J, **Abbott AG**, and FV Hebard. 2018. Update on the Chinese Chestnut Genome Project, NE-1333 Meeting, Pennsylvania State University, University Park, PA, September 7, 2018.
- Carlson JE, **Staton ME**, Addo-Quaye C, Cannon N, **Zhebentyayeva T**, Islam-Faridi N, Yu J, Huff M, **Shenghua F**, **Conrad A**, Schuster SC, **Abbott AG** Westbrook J, Holliday J, **Nelson CD**, and FV Hebard. 2018, The Chinese Chestnut Genome V2.0, International Union of Forest Research Organizations International Workshop Tree Resistance to Insects & Diseases: Putting Promise into Practice, Mt. Sterling, OH, August 5 - 10, 2018.

7. White oak genetics and genomics

Within the past several years we have made substantial inroads into developing and implementing a genetic improvement program for white oak (*Quercus alba*). In this regard, we have hired Dr. Laura Dewald, a tree improvement specialist, in cooperation with the Kentucky Division of Forestry, to spearhead a white oak improvement breeding program. We are continuing to support Rachel Thunder, a graduate student working on studying the impacts of forestry practice on diversity of the species and we have recently initiated a white oak genome sequencing project with Dr. Seth Debolt, (UK Horticulture) and the Kentucky Spirits Institute. Finally, both the biological sciences research team and the outreach and education team are directly involved in a multi-institutional proposal submitted to USDA-NIFA on white oak sustainability.

8. Other presentations and publications

Presentations

C.D. Nelson:

1. Torrey tree of life workshop (3/1-2/18), Quincy, FL (Invited)
 - a. Prepared and presented Invited talk “Saving the Trees for the Forest”
 - b. Led genetics/resistance working group discussion, prepared summary
2. USFS Tree Breeding USDA-OCS seminar, Washington DC, Yates Bldg (Invited)
 - a. Co-prepared (with Jennifer Koch and Richard Sniezko) and co-presented seminar (4/5/18)
 - b. Asked for proposal to re-design For Genetics/Tree Improvement in the USFS
 - c. Draft in progress
3. Tree resistance workshop (8/5-8/18), Mt. Sterling, OH
 - a. Two volunteered talks—
 - i. Collaborative Approaches in Forest Health R&D
 - ii. Characterization of the *Fr1* gene in loblolly pine

Publications:

- Potter CKM AR Campbell, SA Jossierand, **CD Nelson**, and RM Jetton. 2017. Population isolation results in unexpectedly high differentiation in Carolina hemlock (*Tsuga caroliniana*), an imperiled Southern Appalachian endemic conifer. *Tree Genetics & Genomes* 13:105 DOI 10.1007/s11295-017-1189-x (20 pages) (refereed)
- Santos C, **Nelson CD**, Machado H, Gomes-Laranjo J, and R Costa. 2017. First interspecific genetic linkage map for *Castanea sativa* x *Castanea crenata* revealed QTLs for resistance to *Phytophthora cinnamomi*. *PlosONE* 12(9): e0184381. <https://doi.org/10.1371/journal.pone.0184381> (refereed)
- Samuelson L, Johnsen K, Stokes T, Anderson P and **CD Nelson**. 2018. Provenance variation in *Pinus palustris* foliar delta13C. *Forests* 9:466, DOI 10.3390/f9080466 (13 pages) (refereed)

- **Nelson CD** and JL Koch. 2017. Institute of Forest Tree Breeding: Improvement and Gene Conservation of Iconic Tree Species in the 21st Century. In: Gene conservation of tree species—banking on the future. Proceedings of a workshop. Gen. Tech. Rep. PNW-GTR-xxx. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 5 p.
- **Smith KE**, Hughes MA, Echt, CS, Jossierand, SA, **Nelson, CD**, Davis JM and JA Smith. Using Genetic Information to Inform Redbay Restoration in Laurel Wilt Epidemic Areas. In: Gene conservation of tree species—banking on the future. Proceedings of a workshop. Gen. Tech. Rep. PNW-GTR-xxx. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 5 p.
- Pere Arús, María José Aranzana, Veronique Decroocq, Elisabeth Dirlewanger, Iban Eduardo, Zhongshan Gao, Ksenija Gasic, Amy Iezzoni, Sook Jung, Cameron Peace, Umberto prieto, Ryutaro Tao, Ignazio Verde, and **Albert Abbott**. 2018. Book chapter: Prunus genetics and applications after de novo genome sequencing: achievements and prospects, Manuscript Number: HORTRES-01585R, 2019

Social Sciences Team Summary

The Social Sciences Team of the FHC’s main goal is to foster understanding of the social and economic impacts of forest health challenges and forest management responses, at local, regional, national, and global levels.

Following the recruitment of new Social Sciences Team members from previous year, the team leader scouted for three forestry faculties to be members of Social Sciences Team Advisor Board. These are Dr. Sayeed Mehmood (Ohio State University), Dr. John Munsell (Virginia Tech), and Dr. Rajan Parajuli (North Carolina State University). Detailed information about this new Advisory Board will be available on social sciences team webpage. The role of the Advisory Board is strategic guidance, visioning, and planning for the team to meet its short, medium, and long term goals. The team will from time to time engage and consult with the board on priority agenda-setting, potential funding sources, among others.

Following successful recruitment of the Advisory Board, the team leader consulted with them and solicited their opinions on the following areas:

- What are topmost critical and urgent issues to focus on, in order of priority?
- Some issues are local (KY), others are regional (southeast US), while some are national (entire US). How should these be prioritized in our work?
- Forest health issues can have short-term, medium term, and long-term impacts. How should we prioritize?
- What are some local funding sources (within state) that can support our work?

- What strategies should we use to ensure that we work closely with landowners and industry stakeholders – to ensure that the research we do directly address issues of concern to them?
- What strategies can we use to ensure maximum benefit/synergy from/among team affiliates (i.e. those from other institutions other than UK and SRS)?

During 2018, the Social Sciences Team research agenda remained focused the following specific projects:

- Delphi expert opinion survey of oak threats and their potential impacts – this was completed and a manuscript is undergoing review with high chances of publication acceptance in Journal of Forestry. Results from this analysis will provide baseline for economic analysis to follow.
- Identifying the Strengths, Weaknesses, Opportunities, and Threats (SWOT) of White Oak Supply. This was completed and a manuscript is undergoing review with high chances of publication acceptance in Journal of Forestry.
- Water-related ecosystem services assessment in Kentucky was completed. One manuscript has already been published - “Impact of land use and climate change on water-related ecosystem services in Kentucky, USA” *Ecological Indicators 102:51-64*. (to be reported for 2019 activities). Two additional manuscripts from this project are almost completed for submission.
- Determinants of perceived risk and liability concerns associated with prescribed burning in the United States. This project was completed and manuscript published (see publications section).

Social Sciences Team Research Presentations/Meetings:

- Bai Y, **Ochuodho TO**, and J Yang. 2018. Impact of Land Use and Climate Change on Water-related Ecosystem Services in Kentucky. Forest Health Research and Education Center Annual Meeting April 24-25, 2018. Lexington, Kentucky.
- Agyeman DA, **Ochuodho TO**, O Joshi. 2018. Sectoral Aggregation Bias in Economic Contribution and Impact Analyses: Evidence from Kentucky Forest Sector. Society of American Foresters 2018 Annual Convention. Portland, Oregon. October 2-7, 2018.
- **Ochuodho TO**. 2018. Underutilized Wood Symposium to Address Energy Development Opportunities. West Virginia University, Morgantown, West Virginia, April 30 - May 1, 2018.
- Olale E, **Ochuodho TO**, Lantz V, J El Armali. 2018. Environmental Kuznets Curve Model for Greenhouse Gas Emissions in Canada. Conference presentation at the International Society of Forest Resource Economics 2018 Annual Conference. Gatlinburg, Tennessee. March 19- 21, 2018.

- **Thomas W**, Niman C, Springer M, Lhotka L, and **T Ochuodho**. 2018. Woodland Owners and Forest Industry Perceptions of White Oak Supply. 11th Association of Natural Resource Extension Professionals Conference. Biloxi, MS. April 29 - May 3, 2018.
- **Thomas W**, Niman C, Springer M, Lhotka L, and **T Ochuodho**. Stakeholder Perceptions of White Oak Supply in Kentucky: A SWOT-AHP Analysis. Forest Health Research and Education Center Annual Meeting April 2018, Ohio Valley Lumber Drying Association Annual Meeting March 2018, 2018 Kentucky Woodland Owners Association Annual Meeting March 2018, Kentucky/Tennessee Society of American Foresters at Natural Bridge State Park June 2018 and the White Oak Initiative Research Collaborative October 2018.
- **Thomas W**. Ash Disaster in Kentucky. Kentucky Woodland Owners Association Annual Meeting at General Butler State Park. March 2018.
- **Thomas W**. Emerald Ash Borer Strategic Planning: the Kentucky Case Study. Southern Group of State Foresters, Lexington, KY, January 2018.

Social Sciences Team Research Publications:

- **Joshi O, Poudyal NC**, Weir J, Fuhlendorf SD, and **TO Ochuodho**. 2019 (Available online 5 October 2018). Determinants of perceived risk and liability concerns associated with prescribed burning in the United States. *Journal of Environmental Management* 230:379-385.
- Withey P, Lantz VA, **Ochuodho TO**, Patriquin MN, Wilson J, and M Kennedy. 2018. Economic impacts of conservation area strategies in Alberta, Canada: A CGE model analysis. *Journal of Forest Economics* 33:33-40. <https://doi.org/10.1016/j.jfe.2018.10.004>.
- Banerjee O, Cicowiez M, **Ochuodho TO**, Masozera M, Wolde B, Lal P, Dudek S, and JRR Alavalapati. 2018. Financing the Sustainable Management of Rwanda's National Protected Areas. *Journal of Sustainable Tourism*. <https://doi.org/10.1080/09669582.2018.1456541>
- Olale E, **Ochuodho TO**, Lantz V, and J El Armali. 2018. Environmental Kuznets Curve Model for Greenhouse Gas Emissions in Canada. *Journal of Cleaner Production* 184:859-868.

Outreach and Education Team Summary

The goals of the Outreach and Education Team are to increase awareness of forest health challenges, improve understanding of the new genetic technologies available for improving and restoring forest health, and promote the work of the FHC. This team is lead by Dr. Ellen Crocker and focuses include engaging concerned citizens, forest owners, and forest industries to better 1) understand and prioritize forest health concerns, 2) develop educational strategies to address these concerns and 3) engage with forest researchers to help define meaningful research avenues and utilize research results to develop solutions to forest health issues. This includes:

- Increasing public and professional understanding of forest health
- Developing and promoting the TreeSnap citizen science app for forest tree research
- Enhancing forest health curriculum, student training, and engagement of underrepresented students
- Increasing understanding of biotechnology's potential in forest restoration
- Increasing awareness of the importance of urban forests
- Sharing and applying the research of the FHC

There have been several major developments for the Outreach and Education team this year, in particular the creation of a new faculty position at the University of Kentucky in Forest Health Extension, being filled by Crocker in Feb 2019, which will contribute to long-term FHC leadership in this area. In addition, the Outreach and Education Team received a USDA RREA grant to develop a woodland health educational tool for landowners, one of the major suggestions from our stakeholders at the 2018 FHC meeting.

During this time period, the Outreach and Education team reached over 1330 people by in-person or webcast educational programming related to invasive species, fungi, citizen science, and other forest health topics. In addition, this team has interfaced regularly with both the biological sciences team and the social sciences team and organized the second annual FHC with FHC members, collaborators, and stakeholders. The FHC Outreach and Education team strives to engage with a more general audience of adults and youth regarding the importance of healthy trees and forests, including those in urban areas. Over 60 university students were engaged through classes and 2 university undergraduates were mentored.

The Outreach and Education Team's TreeSnap app citizen science project (collaboration with Meg Staton, University of Tennessee) continues to grow (www.TreeSnap.org). This app connects members of the public to restoration tree breeding programs throughout the country including those working to identify trees surviving invasive insects and pathogens for use in breeding programs. This app, freely available for iPhone and Android, has attracted over 2089 users and collected 2903 tree observations from 40 states and numerous other countries around the world since its release in July 2017.

Outreach and Education Team Publications (*bold names indicate FHC-affiliated*):

- **Crocker E**, Bordas A and D Coyle. 2018. Biology, Ecology, and Management of Biscogniauxia (Hypoxylon) Canker in the Southeastern U.S. SREF Factsheet, SREF-FH-009
- **Crocker E**, Moore H, Niman C, and **J Stringer**. 2018. White Paper on Ambrosia Beetle Damage to Dead Ash in KY: Prevalence and Economic Impact to Loggers in Northern Kentucky. University of Kentucky, College of Agriculture, Food, and the Environment, Department of Forestry and Natural Resources - Extension

Outreach and Education Team Programs Organized:

- **Crocker E.** Assisted in organizing Forest Health Research and Education Center Annual meeting and Research Symposium, April 2018, Lexington, KY, 35 people
- **Crocker E.** Assisted in organizing the 4th annual UK Society of Postdoctoral Scholars Annual Research Symposium and facilitated panel discussion on careers post PhD, June 2018, Lexington KY, 75 people
- **Crocker E.** Organized TreeSnap Partners Meeting, June 2018, 15 people
- **Crocker E.** Assisted in organizing the 6th International Workshop on the Genetics of Tree-Parasite Interactions: Resistance to Insects and Diseases: Putting Promise into Practice, August 5-10, 2019, Mt. Sterling OH, 100 attendees
- **Crocker E.** Organized the KY Expanding Your Horizons STEM conference for middle school girls, April 2018, 160 middle school girls, 30 parents, 100 UK undergraduate and graduate students

Outreach and Education Team Courses Taught:

- **Crocker E.** Instructor, NRE 390, Introduction to Urban and Community Forestry, Fall 2018, 14 undergraduate students
- **Crocker E.** Guest lectured “Biotechnology and Forestry,” FOR 400 Human Dimensions of Forestry and Natural Resources, Fall 2018, 12 undergraduate students
- **Crocker E.** Instructor, FOR 310 Introduction to Forest Health and Protection, Spring 2018, 13 undergraduate students
- **Crocker E.** Instructor, EXP 396 Engaging Girls in STEM: Leadership and Service Learning for the Expanding Your Horizons Conference, Spring 2018, Experiential Education, University of Kentucky, 20 undergraduate students
- **Crocker E.** Instructor, EXP 650 Engaging Girls in STEM: Leadership and Service Learning for the Expanding Your Horizons Conference, Spring 2018, Experiential Education, University of Kentucky, 5 graduate students

Outreach and Education Team Presentations:

- **Crocker E.** “Fantastic fungi!” lesson with elementary students from Booker T Washington STEM Club, Lexington KY, Dec 17, 2018, 5 people
- **Crocker E.** “Citizen Science” radio show on From the Woods Kentucky Program, WRFL Lexington KY, Dec 6, 2018
- **Crocker E.** Organized and facilitated meeting of KY Forest Health Task Force, Frankfort KY, Dec 5, 2018, 30 people
- **Crocker E.** Organized and facilitated “Seeing the Forest Through the Trees: A Panel Discussion and Public Forum on Tree Inventories,” Lexington, KY, Nov 28, 2018, 70 people
- **Crocker E.** “Managing Invasive Species” workshop led for KY Master Naturalist student group, Lexington KY, Nov 2, 2018, 20 people

- **Crocker E.** “Introduction to Fungi” talk given to WildOnes group, Lexington KY, Nov 1, 2018, 40 people
- **Crocker E.** “Introduction to Invasive Species” class led for KY Master Naturalist student group, Lexington KY, Oct 31, 2018, 15 people
- **Crocker E.** “Foods of the Forest” demonstration at UK Fresh Food Company Dinning Hall, Lexington KY, Oct 25, 2018, 100 people
- **Crocker E.** “Program Development and Delivery Module 2” presentation as a part of the Seeding Success Extension agent onboarding training webinar series developed by Southern Regional Extension Forestry, <https://sref.info/seedingsuccess/module4/>, Oct 23, 2018
- **Crocker E.** “Program Development and Delivery Module 1” presentation as a part of the Seeding Success Extension agent onboarding training webinar series developed by Southern Regional Extension Forestry, <https://sref.info/seedingsuccess/module4/>, Oct 16, 2018
- **Crocker E.** “White Oak Threats” presentation at the annual Associated Cooperage Industries of America meeting, Austin TX, Oct 15, 2018, 75 people
- **Crocker E.** “Introduction to Invasive Species” workshop led for KY Master Naturalist group, Louisville KY, Oct 11, 2018, 15 people
- **Crocker E.** “Revisiting Floracliff’s Old Oaks: A TreeSnap Training and Citizen Science Workshop” led at Floracliff Nature Sanctuary, Lexington KY, Oct 2018, 15 people
- **Crocker E.** Judging of invasive plant identification competition at Win With Wood youth event, Jackson KY, Oct 2, 2018, 100 people
- **Crocker E.** “Invasives of the Future” presentation at the Invasive Plant Species Management Techniques Workshop for Land Managers hosted by KY Chapter of the Wildlife Society, Sept 19, Richmond, KY, 75 people
- **Crocker E.** “Citizen Science Apps” workshop at Mountain Ag Day, Clayhole, KY, Sept 18, 2018, 20 people
- **Crocker E.** “Citizen Science” workshop led at the annual Kentucky Environmental Educators conference, Berea KY, Sept 7, 2018, 10 people
- **Crocker E.** “Introduction to KY Master Naturalist Program” presentation at the annual Kentucky Environmental Educators conference, Berea KY, Sept 7, 2018, 35 people
- **Crocker E.** “Forest Health” radio show on From the Woods Kentucky Program, WRFL Lexington
- **Crocker E.** Tree health concerns interview by WKYT TV station, Lexington KY, Aug 30, 2018
- **Crocker E, Condon B, Abdullah A, Abbott A, Nelson CD, and M Staton.** TreeSnap: a citizen science tool to help our forests. Presentation at Tree Resistance Workshop, Aug 9, 2018. 100 people
- **Crocker E.** “Introduction to Invasive Plants and their Management” talk, Shelby Co. Master Gardeners, Shelbyville KY, July 26, 2018, 20 people

- **Crocker E.** “Tree Detectives” activity, 4H Natural Resource & Environmental Sciences Academy, Lexington, KY, July 24, 2018, 15 people
- **Crocker E.** “TreeSnap Citizen Science Sampling Day” event, Floracliff Nature Preserve, Lexington KY, July 12, 2018, 20 people
- **Crocker E.** Organized “Forests of the Future” seminar with 4 invited speakers Fayette Co. Cooperative Extension Office, Lexington KY, July 11, 2018, 70 people
- **Crocker E.** “Mushroom Identification” talk and hike, Kenton Co. Cooperative Extension, Ft. Mitchell KY, June 22, 2018, 15 people.
- **Crocker E.** “Forest pathology” seminar, Kentucky 4H Forestry Team, Lexington KY, June 19, 2018, 10 people.
- **Crocker E.** “We Speak for the Trees” mini-course, 4H Teen Conference, Lexington KY, June 12-13, 2018, 10 people.
- **Crocker E.** “Introduction to Forest Health” talk, Kentucky Forest Leadership Program, Jabez KY, June 4, 2018, 20 people.
- **Crocker E.** “What to Expect When You Are Expecting EAB” talk, Clemson University, Clemson SC, May 23, 2018, 20 people.
- **Crocker E, Condon B, Abdullah A, Abbott A, Nelson CD, and M Staton.** TreeSnap: a citizen science tool to help our forests. Presentation at Association of Natural Resource Extension Professionals (ANREP) meeting, Biloxi MI, May 2, 2018, 30 people.
- **Crocker E, Conrad A, Thomas W, Li X, Ochuodo T, Holmes, T and CD Nelson.** Delphi expert opinion survey to assess threats to oaks in the eastern United States. Poster presentation at Association of Natural Resource Extension Professionals (ANREP) meeting, Biloxi MI, May 1, 2018, 50 people.
- **Crocker E.** Hosted KY Expanding Your Horizons STEM conference for ~160 middle school girls, Lexington KY, April 21, 2018, 240 people.
- **Crocker E.** “Woodland mushroom cultivation and identification” workshop, Lyon Co. Cooperative Extension Office, Grand Rivers KY, April 5, 2018, 20 people.
- **Crocker E.** “Fungus Among Us” activity at Nerd Squad Park takeover event with elementary and middle school students, Lexington KY, April 6, 2018, 10 people.
- **Crocker E.** “Urban tree health and diagnostics” talk to UK TreeCATS program, Lexington KY, March 31, 2018, 20 people
- **Crocker E.** “Asian Longhorned Beetle and Other Invasives to Watch For” talk to Kentucky Woodland Owners Association, March 21, 2018, 30 people.
- **Crocker E.** “Ambrosia beetle damage to standing dead ash trees” talk in KY Master Logger TV, Feb. 6, 2018.
- **Crocker E, Condon B, Abdullah A, Abbott A, Nelson CD, and M Staton.** TreeSnap: a citizen science tool to help our forests. Seminar at UK Forestry and Natural Resources Department Seminar Series, University of Kentucky, Feb. 21, 2018, 20 people.