**PROJECT ID:** CAFS. 20.80.

**YEAR:**  **4** of

**PROJECT TITLE:** Using hyperspectral imaging to evaluate forest health risk

**INVESTIGATOR(S):** John Couture, Melba Crawford, Matthew Ginzel, Brady Hardiman Douglass Jacobs (Purdue University), Aaron Weiskittel, Parinaz Rahimzadeh, Peter Nelson (University of Maine), Cristian Montes, Caterina Villari and Kamal Gandhi (University of Georgia)

|  |
| --- |
| **PROJECT DESCRIPTION:**  Managed forest systems are important contributors of terrestrial biomass productivity and carbon storage. Currently, forest systems face a diverse array of stressors of a scale and complexity previously unobserved. Incorporating digital approaches into forest monitoring and management has potential to mediate the negative impact of stressors on forests. Of the data forms potentially generated in digital forestry efforts, hyperspectral data is capable of rapidly generating tree biochemical and physiological status, especially in response to stress. While hyperspectral monitoring is more frequently incorporated into row cropping systems, hyperspectral data has been largely underutilized in forest management practices, distilling information into indexes, such as NDVI (plant greenness), and not focusing on stress-specific responses. In this project, we propose to: 1) determine the ability of hyperspectral data to provide information related to tree status in response to abiotic and biotic stress, 2) assess the reliability of hyperspectral information to scale from leaf, to tree, to stand level measurements, and 3) evaluate the validity of hyperspectral data to characterize stress responses over different spatial scales in varying geographic locations. Our preliminary findings indicate that hyperspectral data can accurately and precisely predict tree responses to environmental variation and disease status, suggesting that combining high-resolution hyperspectral data with high-fidelity reference measurements can provide a framework to monitor stress-specific responses, creating response windows that enable efficient and cost-effective management decisions. This project will require cross-site collaboration and sharing of data of remotely sensed and empirical field data. |
| **HYPOTHESES or OBJECTIVES:**  ● Determine the ability of hyperspectral data to 1) quantify tree foliar chemical and physiological responses to abiotic and biotic stress, 2) detect induced plant defense responses to insect herbivory under greenhouse conditions, and 3) quantify growth and physiological responses of black walnut seedlings to drought under field conditions. Using hyperspectral data paired with standard analytical measurements, we propose to characterize tree responses to a variety of abiotic and biotic stressors (**Objective 1**).  ● Assess the reliability of hyperspectral information to scale from leaf, to tree, to stand level measurements. We will collect high-fidelity hyperspectral data across multiple spatial scales (from leaves to trees to stands) and determine the precision and accuracy of the measurements at the different spatial scales to better understand how this data may help to inform managers of stress events (**Objective 2**).  ● Integrate multi-spatial and temporal scale remote sensing (RS) products with forest management scenarios. Specifically, we will focus on three areas of forest management: 1) tracking insect pest and pathogen incidence, severity, and spread, 2) early detection of drought stress related symptoms, and 3) optimizing RS acquisitions to determine the number of collections appropriate to make informed management decisions (**Objective 3**). |
| **METHODS:**  To address the question of trait retrieval and phenotyping accuracy using hyperspectral data, we quantified abiotic and biotic stress in black walnut (*Juglans nigra* L.), a high-value hardwood tree species in central and eastern forest regions of the USA, under a controlled environment in a greenhouse setting and in the field. Seedlings of black walnut were exposed to the different combinations of abiotic and biotic stressors, including fungal infection, drought, nutrient deficiency, and salt deposition in a greenhouse in 2018 and 2019 (Objective 1\_1). Black walnut seedlings were grown under three different nitrogen levels in a greenhouse. Second-instar larvae of luna moth (*Actias luna* L.) were put onto foliage to expose the tree seedlings to herbivory stress in 2020 (Objective 1\_2). Black walnut seedlings were grown under drought preconditioning in a greenhouse for one year and transplanted into the field. At this site, we exposed the seedlings either to irrigated or non-irrigated (drought) conditions during the dry season of summers of 2021 and 2022 (Objective 1\_3). We conducted leaf-scale measurements of functional traits related to those stressors using both standard reference measurements and hyperspectral measurements. Reference measurements included water relations (e.g., water potential, relative water content, water use efficiency) and photosynthesis (e.g., assimilation, conductance, nitrogen concentrations) along with biochemical measurements of tree stress responses (e.g., foliar phenolic compounds, lignin). We built predictive models to estimate these leaf traits as a function of leaf spectra using a partial least square regression (PLSR) approach. In addition, we examined the effect of different wavelength ranges on the outcomes of PLSR models.  We used the permutational multivariate analysis of variance, the principal coordinates analysis and the partial least squares-discriminant analysis to determine if the spectral data can classify different stress treatment groups. We also used RELEF-F algorithm to extract significant and most relevant wavelengths which describe the impact of stressors on black walnut leaves.  To address the question of scalability of hyperspectral products in Objective 2 and to link RS products with forest management scenarios in Objective 3, we will collect spectral data at leaf and canopy scales in forest plantations under biotic (pests, pathogens), and abiotic (i.e., drought) stressors. Above canopy spectral collections will be acquired using UAV-based hyperspectral imagery and will be collected three-four times per year. RGB (Red, Green and Blue band of RS images) will be used as assess visible top of canopy stress and identify individual trees, while LiDAR will be used to segment canopy from understory measurements and determine canopy structural integrity. Hyperspectral data will be used to map functional traits using partial least squares regression weighted for canopy stratification and identify stress prior to the onset of visual symptoms. The integrated RS data sources and functional trait outputs derived from the maps will be included in multiple machine learning approaches to develop classification algorithms to classify tree stress status. At each time of RS acquisition, we will census for biotic and abiotic stress responses with ground reference measurements and fine-scale chemical and physiological measurements (i.e., functional traits) will be collected from canopy leaves from different positions. These measurements will help inform the RS data in the machine learning models. |
| **MAJOR FINDINGS:**  ● The inclusion of short infrared wavelength ranges (1300−2400 nm) was essential in enhancing the prediction of six major leaf traits (CO2 assimilation rate, leaf water content, specific leaf area, nitrogen, sugars, and gallic acid) using PLSR. The choice of the starting or ending wavelength in a specific spectral range was associated with the model’s performance in a characteristic way depending on the trait being predicted, and the association was explained by the absorption features of the leaf trait.  ● Most of the PLSR models reliably estimated most black walnut leaf functional traits with external validation goodness-of-fit (*R*2) ranging from 0.25 to 0.95 and normalized error ranging from 6% to 22%, where the highest *R*2 was seen in leaf water content (%) and the lowest *R*2 was found in leaf carbon concentration (%).  ● Spectral data classified different individual stress groups well, but the ability of spectral data to classify stress groups depended on if the stress events were applied individually or in combination.  ● Distinctive relative changes in leaf spectra were observed across different stress groups, resulting from the different impacts of stressors on tree biochemical and physiological changes.  ● Herbivory treatment affected the reflectance profile of black walnut, whereas no significant effects were found in the control group. However, shifts of leaf spectral data in response to herbivory stress occurred with varying degrees of change depending on soil nitrogen availability.  ● Spectral data identified different groups in drought treatment under field conditions, but the change of spectral data to field drought treatment was affected by seedling drought preconditioning. |
| **DELIVERABLES:**  Two papers are in progress currently, and six oral and four poster presentations have been given from this project.  – In progress  1. Park S, Cotrozzi L, Jacobs DF, Couture JJ. *In preparation*, Assessing the influence of wavelength ranges on chemometric modeling outcomes for estimating key foliar functional traits. *Methods in Ecology and Evolution*  2. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. *In preparation*, Spectral assessment of chemical and physiological responses of hardwoods to various stresses.  – Oral Presentations  1. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2020.10.13. Characterizing abiotic and biotic stress using hyperspectral information. HTIRC 2020 Advisory Committee Meeting (Virtual).  2. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2020.08.03–06. Quantifying tree foliar chemical and physiological responses to abiotic and biotic stress using hyperspectral data. 2020 ESA Annual Meeting (Virtual).  3. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2021.11.16. Characterizing abiotic and biotic tree stress using hyperspectral information. Digital Forestry Grad Student Meeting (Virtual).  4. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2022.12.12–16. Characterizing tree chemical and physiological responses to abiotic and biotic stress using hyperspectral information. 2022 AGU Fall Meeting. Chicago, IL & Online  5. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2023. 02. 24. Characterizing Tree Chemical and Physiological Responses to Abiotic and Biotic Stress using Hyperspectral Information. HTIRC 2023 Annual Meeting. John S. Wright Forestry Center, West Lafayette, IN.  6. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2023. 03. 04. Characterizing Tree Chemical and Physiological Responses to Abiotic and Biotic Stress using Hyperspectral Information. Digital Forestry Mini Symposium. Lawson Hall, Purdue University, West Lafayette, IN.  – Poster Presentation  1. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2021.04.09. Hyperspectral analysis of tree foliar chemical and physiological responses to abiotic and biotic stress. FNR Poster Competition (Virtual).  2. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2021.10.15. Hyperspectral analysis of tree foliar chemical and physiological responses to abiotic and biotic stress. HTIRC 2021 Annual Meeting. John F. Wright Forestry Center.  3. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2022. 05. 26. Hyperspectral analysis of tree foliar chemical and physiological responses to abiotic and biotic stress. Center for Plant Biology Retreat. Beck Agricultural Center, West Lafayette, IN.  4. Park S, Cotrozzi L, Williams GM, Ginzel MD, Mickelbart MV, Jacobs DF, Couture JJ. 2022. 08. 08. Hyperspectral analysis of tree foliar chemical and physiological responses to abiotic and biotic stress. Digital forestry retreat. John S. Wright Forestry Center, West Lafayette, IN. |
| **MEMBER COMPANY BENEFITS:**  This project will generate outcomes that can directly inform potential management decisions involving forest plantation management through more efficient and specific characterization of tree health using RS data. This project will be at a national-scale and will be relevant for all industry members. |