**Center for Advanced Forestry Systems**
**2021 Annual Meeting Project Progress Report**



**PROJECT ID:** CAFS.20.80

**YEAR:** 2 of

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

**INVESTIGATOR(S):**

**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 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.

Description of project goal and approach
From original or continuation proposal with updates if necessary

**HYPOTHESES or OBJECTIVES:**
**Objective 1_1) Quantifying tree foliar chemical and physiological responses to abiotic and biotic stress using hyperspectral data:** Determine the ability of hyperspectral data to provide information related to tree status in response to abiotic and biotic stress. Using hyperspectral data paired with standard analytical measurements, we propose to characterize tree responses to a variety of abiotic and biotic stressors.
**Objective 1_2) Hyperspectral detection of induced plant defense responses to insect herbivory:** Determine the influence of different fertilizer regimes on walnut foliar chemical composition and determine if those changes influence the performance of luna moth (*Actias luna* L.). Develop a hyperspectral method to detect induced plant defense responses to insect herbivores.
**Objective 2)** 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 3):** 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.

From original or continuation proposal with updated status

**METHODS:**

In Objective 1_1, we focused on black walnut (*Juglans nigra* L.) and red oak (*Quercus rubra* L.) which are high-value hardwood tree species in central and eastern forest regions of the USA. Seedlings of two species were exposed to the different combination of abiotic and biotic stressors, including fungal infection, drought, nutrient deficiency, and salt deposition in a greenhouse under a controlled environment, and then we conducted leaf-scale measurements of functional traits related to those stressors using both standard reference measurements and hyperspectral measurements. Reference measurements include 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. We used the permutational multivariate analysis of variance and the principal coordinates analysis to see if the spectral data can classify different stress treatment groups. In Objective 1_2, three groups of black walnut seedlings were grown under three different nitrogen levels in a greenhouse. Second-instar larvae of luna moth were put onto foliage and then collected leaf spectra data and biochemical traits from damaged leaves, undamaged leaves of insect-damaged seedlings, and undamaged seedlings. 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 resulting PLSR models reliably estimated most black walnut and red oak leaf functional traits with external validation goodness-of-fit ($R^2$) ranging from 0.37 to 0.90 and normalized error ranging from 7.5% to 18.3%.
- 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.

- Herbivory treatment affected the reflectance profile of black walnut, whereas no significant effects were found in the control group.

**DELIVERABLES:**

Two oral and one poster presentations have been given from this project.
– Oral Presentations
**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).
**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).
– Poster Presentation
**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).

**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.