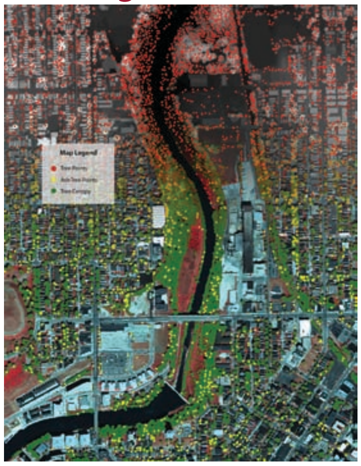
NCDC Imaging contracted with Terra Remote Sensing Inc (TRSI) for the acquisition of 1-meter resolution narrowband (5 nm) hyperspectral imagery and accompanying lidar over Milwaukee, Wisconsin (95 square miles). Reflectance spectra of representative tree species were collected in the field using a FieldSpec® 3 spectroradiometer system from ASD, Inc.

NCDC analysts used a LiDAR-derived digital surface model and a 4-band multispectral image that was derived from the hyperspectral imagery to create an accurate tree canopy polygon dataset. The canopy spectral signatures collected with the ASD FieldSpec 3 spectroradiometer were then utilized in conjunction with the hyperspectral imagery to classify Ash trees over the study area. The hyperspectral imagery was evaluated for detection of imperceptible stress in ash species as a tool for rapid early detection for emerald ash borer. The red points shown on the cover image are the tree points for all trees in the given area. The green polygons display the tree canopy in the same area and lastly the yellow points represent the Ash trees.



The cover image and corresponding highlight article are sponsored by ASD Inc. of Boulder, Colorado, manufacturer of the rugged and truly portable FieldSpec 3 line of spectroradiometers (www.asdi.com).

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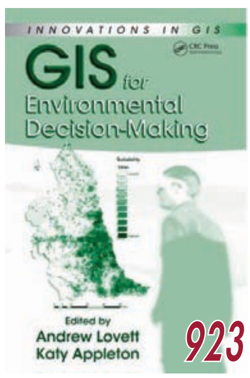

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High-Resolution Remote Sensing Image Analysis for Early Detection and Response Planning for Emerald Ash Borer

by Jason San Souci, Ian Hanou, and Daniel Puchalski

Introduction

In February 2007, the City of Milwaukee Forestry Division began talks with Native Communities Development Corporation Imaging (NCDC), on a unique project that would enable the City to better prepare for, and respond to, the emerald ash borer (EAB). The EAB is a small exotic beetle that has killed tens of millions of ash trees in Michigan and surrounding states since first found near Detroit, Michigan in 2002. An Urban Forest Effects (UFORE) ecosystem analysis completed in 2008 estimated Milwaukee's ash tree population at 16 percent of the total urban tree canopy. A map of the location and quantity of EAB host distribution across the City would be critical in planning, budgeting, education and management of this pest to prevent a total loss of ash canopy and associated environmental, social, and economic benefits. The City and NCDC determined that hyperspectral imaging (HSI) technology would be an accurate and cost-effective approach to capturing ash tree distribution to provide homeowners, businesses, and utility and city departments with information that would better prepare them for EAB. The results of the hyperspectral data analysis would then be combined with NCDC's lidar (Light Detection And Ranging) and GIS analysis capabilities to provide measurable results and outcomes on a meaningful scale which will have positive changes on the ground and in policies that guide the management of invasive species. While high-resolution, airborne hyperspectral imagery has been used for vegetation species mapping in the past, and lidar data has successfully been used for urban tree canopy mapping, this project represented an opportunity to integrate the two unique data sources into a single information resource for the City's Forestry Division.

Figure 1. In field handheld spectrometer data collection. (photos © Robin F. Pendergrast Photography, Inc.)

NCDC Imaging, in collaboration with RFP Mapping LLC. (RFP) who funded the project, assembled a team of industry-leading remote sensing scientists to evaluate and implement the project. This included ASD Inc. (ASD) for field spectrometry hardware and the collection of ground spectral signatures, and Terra Remote Sensing Inc. (TRSI) for airborne HSI, using an AISA hyperspectral sensor and lidar data collection. SRA International, Inc. (SRA) led the hyperspectral data analysis effort to include executing the field-based spectral signature collection campaign, development of analysis methodology, and exploitation of over 600 GB of hyperspectral data. NCDC analyzed the lidar data and conducted final GIS analysis and data fusion of lidar and HSI analysis products for metrics on urban forest structure, performed quality assurance and quality control (QA/QC) on all products and managed the project from its initiation to completion.

The project presented many challenges and an incredible opportunity for the City and all partners involved. As issues relating to forest health, urban forest canopy cover, and environmental sustainability become more complex, urban natural resource managers are required to provide information to the public that addresses health and safety concerns while leveraging tax dollars effectively. Geospatial technologies such as remote sensing and GIS play an increasingly important role in offering accurate, timely, and cost-effective solutions to such new problems.

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The Milwaukee EAB detection project was designed to communicate the public safety risk of Ash trees vulnerable to the invasive Emerald Ash Borer beetle in residential areas. This image illustrates the distribution of host Ash trees throughout residential and business districts in Milwaukee, WI. The City Forestry Division and project team decided to use a combination of hyperspectral and lidar data analysis to map and characterize the extent of the problem which helps the City to create plans for effectively managing their natural resources. Newly developed tools needed for improved species mapping, risk assessment, forest health monitoring, rapid early detection, and management of Emerald Ash Borer were developed and applied in conjunction with high-resolution remotely sensed hyperspectral images and lidar data. This project highlights Milwaukee's progressive leadership and partnership with the nation's top remote sensing and GIS specialists resulting in substantially new best practices for management of highly destructive forest pests through the use of advanced geospatial technologies.

Project Overview

This project applied advanced geospatial technology, including high-resolution remotely sensed hyperspectral images and lidar data, in conjunction with GIS analytical applications, to develop new tools needed for improved species mapping, risk assessment, forest health monitoring, rapid early detection, and management of EAB. The objectives of this project were to:

- Utilize HSI to geospatially map the location and condition of ash species in the City of Milwaukee with 80 percent or greater accuracy.
- Develop replicable protocols for ash species identification in the urban and suburban landscapes utilizing high-resolution, remotely sensed HSI.
- Integrate ash species maps with existing GIS analytical tools to improve targeted inspections and outreach efforts of federal, state, and local officials.
- Evaluate the use of HSI in conjunction with UFORE analysis data for predicting the volume of potential wood waste generated by an EAB outbreak.
- Improve the resolution and accuracy of EAB risk assessment maps.

The project framework consisted of several technical steps. First, multispectral contextual classification provided a quick and comprehensive urban tree canopy map. Hyperspectral target detection and accuracy can be further refined when the tree canopy layer acts as a mask to segment forest area from non-forest area. Through this process only HSI pixels within the canopy layer will be identified as positive ash locations. SRA rescaled the HSI imagery into a four-band multispectral product that NCDC thereafter utilized to derive the base tree canopy layer, as a region of interest, to aid in creating, and for analyzing the ash species maps produced by SRA.

The results and framework established by the project will outline the use of HSI as a tool for geospatial species and stress mapping. Applicable in urban and rural forest settings alike, the deliverables from the project will demonstrate the application of high- resolution, remotely sensed technology for invasive species management, forest mapping, and assessment. It will also serve as the foundation for the development of substantially revised management practices for EAB and other invasive species.

Conducting an HSI analysis simultaneously with an urban tree canopy (UTC) assessment improves existing UTC analyses (such as that pioneered by Jarlath O'Neill Dunne at the University of Vermont Spatial Analysis Lab), by adding new layers of information (species delineation and stress detection) that is useful to resource managers. HSI inventory, coupled with an ecosystem benefits analysis (such as the Urban Forest Effects model (UFORE) or using the CITY green software created by American Forests) and multispectral contextual land cover classification will allow the structural and functional ecological service impacts associated with an EAB infestation to be measured; including pre- and post-EAB air quality, storm water, and energy related canopy benefits. By quantifying the potential effects of EAB on the wood waste stream, communities are better prepared to assess budget impacts and staffing requirements related to early rapid detection, monitoring, treatment, removal, marshalling and reforestation.

Hyperspectral Data Collection and Analysis

For this project, airborne hyperspectral data represented a unique capability to support the classification of green and white ash trees over a large area while addressing some important shortfalls of large-scale inventories and analysis projects. The collection and analysis of airborne spectral imagery from a single integrated HSI and lidar platform ensured that the data collected for the campaign maintained a coherent spatial and temporal framework. Simultaneously, the use of hyperspectral data for tree classification allowed the project to determine and maintain a consistent, measureable accuracy level across the study area and avoid subjectivity that can result from ground inventories conducted over a large time span.

Hyperspectral sensors record hundreds of narrow, contiguous measurements of electromagnetic energy reflected by an object. These measurements represent the electromagnetic "signature" of the target and can be used to identify the specific materials that make up the target based upon their molecular and electromagnetic properties. The use of hyperspectral data continues to increase as commercial hyperspectral data collection becomes more cost effective. In particular, hyperspectral data has become important to natural resource managers to classify vegetation and determine their detailed characteristics, including species, health and stress.

Based on the experience with other vegetation analysis projects, the project team developed a data collection and analysis campaign designed to reduce risk and maintain an aggressive schedule. The spectral collection and analysis campaign was divided into three phases: Field Data Collection and Analysis, Airborne Data Collection and Processing, and Methodology Development and Production.

Figure 2. Adult emerald ash borer in larval tunnel. (Photo courtesy of Eric Day, Virginia Tech, Department of Entomology).

Field Data Collection and Analysis

NCDC, SRA, ASD and RFP Mapping LLC partnered with the Milwaukee Forestry Division to conduct a field spectral data collection campaign focused on gathering field spectra of the ash species of interest and potential tree and vegetation species that may be within the study area. The field data collection campaign (Table 1) consisted of a structured process designed to collect sample spectra of species of interest and surrounding environmental and spatial information in order to support the development of a robust method to detect and characterize green and white ash trees within the Milwaukee area (Figure 2).

The ground campaign team collected a variety of data under a collection region. The spectral signatures were collected under similar conditions expected for the airborne data collection and included both radiance (atmospheric effects included) and reflectance measurements (atmospheric effects removed). Each spectral sample was taken using a full range (350-2500 nm) ASD FieldSpec spectroradiometer taken over multiple areas of the target tree of interest (Figure 3).

Table 1.

Field Spectral Campaign Data

- **Visible to Short-wave Infrared Spectral Signatures (Radiance and Reflectance)**
- **Digital Media (Photos and Video)**
- **GPS Coordinates**
- **Environment and Target Attributes (state of health, adjacent materials, weather conditions)**

Daniel Puchalski, (SRA) said, "I have worked hundreds of target types over the last 13 years using over 20 different spectral sensors and this was the hardest target thus far to separate from its background with limited false alarms. Trees are all made of basically the same material. The difference between an ash tree and some of the other common trees in the Milwaukee area are unbelievably subtle, when you add things like plant health and stage of growth, it is an amazingly complex problem."

Following the collection of field spectra, the project team conducted initial analysis to determine the spectral separability of the target species from other trees and vegetation that are common within the Milwaukee area of interest. The purpose of this step was to verify that the proposed airborne hyperspectral data would provide the required spectral and spatial information to accurately characterize white and green ash. This analysis served as a risk reduction step prior to execution of the full airborne collection campaign.

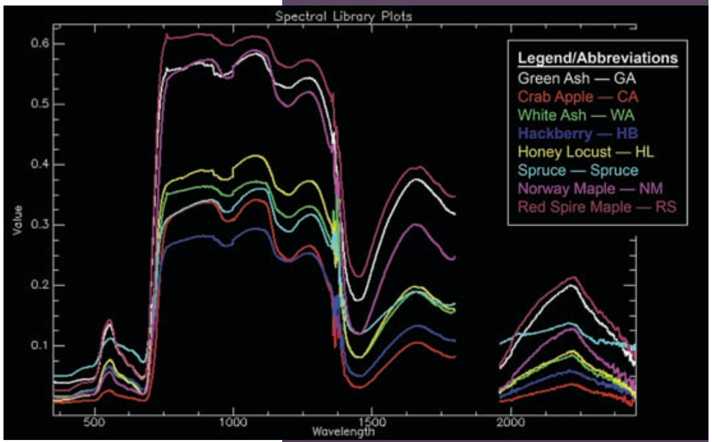

Figure 3. Comparison of Green Ash to 7 potential backgrounds results in 240 significant bands

Airborne Data Collection and Processing

NCDC Imaging contracted with Terra Remote Sensing Inc (TRSI) out of Sydney, British Columbia, Canada for the acquisition of 1-meter resolution narrowband (5nm) hyperspectral imagery and accompanying lidar over the City (95 square miles). The Terra Remote Sensing collection system provides a single platform capable of simultaneous collection of both HSI and lidar data sets. Terra Remote Sensing and their mission partner at the University of Victoria processed the lidar and HSI data for the follow-up analysis by NCDC and SRA.

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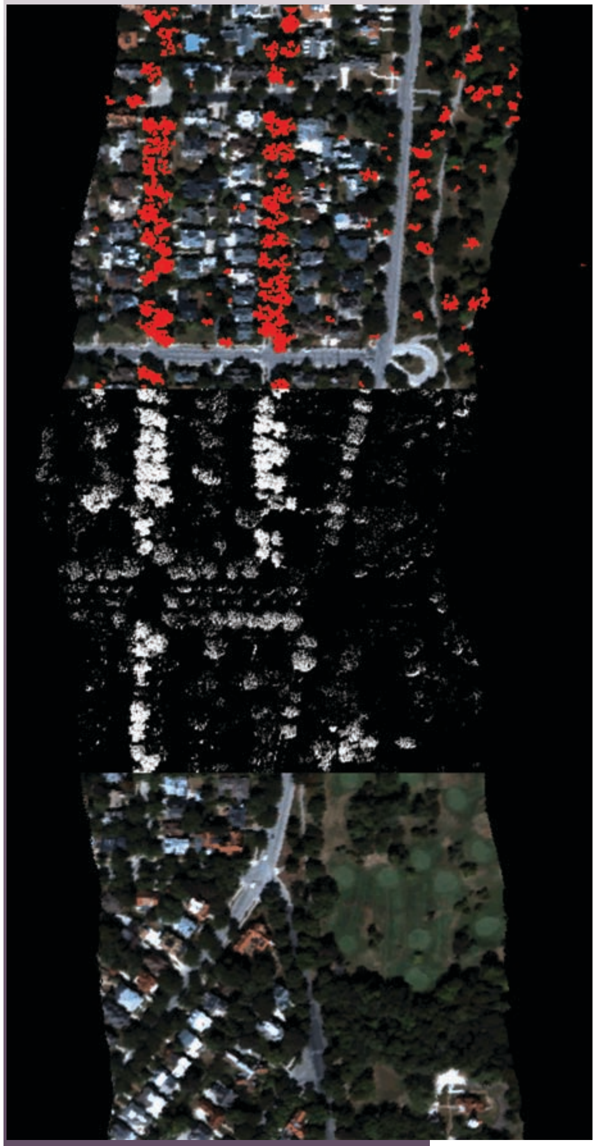

Figure 4. Depiction of Hyperspectral Data and Results. Bottom 1/3 is true-color image of Milwaukee Street, Middle is Output of Spectral Analysis, Top is Detections mapped onto True-Color.

Methodology Development and Production

SRA adapted an established hyperspectral analysis process to detect and characterize white and green ash. The analysis method consisted of two primary tasks – selection of spectral signatures and selection of analysis algorithm and approach.

The analysis team utilized the field collected spectra to develop three signatures for exploitation – white ash, green ash, and common ash (representing a commonality across ash species to improve the detection of some ash variants such as purple ash). The development of these signatures followed an interactive process during which the field collected spectra were compared with the spectra extracted from the hyperspectral data.

Following the adoption of target spectral signatures, Dan Puchalski and Rich Burch modified a proven spectral analysis methodology that the SRA analysis team has successfully used to identify similar plants across variations in state of health or growth stage. The methodology was developed by the team during previous hyperspectral projects including counter narcotics applications. The analysis process relies on the exploitation of radiance data using a process referred to as hyperspectral feature analysis. The hyperspectral feature analysis approach focused analysis on the wavelengths where a spectral contrast between ash trees and background vegetation existed. This process typically works well with radiance or reflectance data and in further lending itself to lower analysis costs and automation of the final spectral exploitation. The use of radiance data for this project avoided adding additional errors based on incorrect atmospheric compensation. While not a problem for some applications, small errors in atmospheric compensation can have dramatic effects on some species discrimination. Atmospheric effects were treated as part of the mixed pixel or sub pixel materials in the spectral matching equation. Finally, the team modified the process with an additional analysis step utilizing a spectral angle mapping process to reduce the potential for false alarms from man-made features and collection artifacts (Figure 4).

The SRA analysis team then worked with NCDC and the Milwaukee Forestry Division to conduct an initial accuracy assessment to ensure that the developed process was accurately detecting green and white ash trees and not producing a large number of false alarms on other trees. This check resulted in a modification of the analysis process by adjusting the contribution of the spectral angle mapping component and provided an increase in classification accuracy.

Following the development of the final analysis methodology, SRA implemented the algorithm as an automated process to efficiently analyze the 600+ GB of hyperspectral data. Final outputs consisted of classification maps of ash trees for use by NCDC in GIS analysis.

Lidar Analysis

NCDC conducted the lidar analysis for this project. Analysts at NCDC needed to produce a bare earth digital elevation model from the one-meter posting lidar data that was both aesthetically pleasing and accurate, i.e., no holes due to water, buildings were removed, and bridges were smoothed out. Once the bare earth DEM was created, NCDC analysts extracted the canopy/crown tops of the trees using the first and last return raster datasets. The resulting datasets included a high precision tree polygon layer and a tree point dataset attributed with tree height, crown width, and stem diameter.

GIS Analysis

Using sophisticated GIS analytical tools, NCDC converted the binary ash raster dataset, from SRA, into a vector data format and intersected the resulting file with the tree points from the lidar extraction, which were buffered by 15 feet. NCDC analysts were then able to select the tree points contained within the tree point buffer and attribute them with a “high” or “low” level of confidence that any particular point was an ash tree based on proximity and size. As a general rule, any tree polygon measuring less than 15 square feet, within the buffered distance would be attributed with a "low" confidence level. Because the tree canopy layer was attributed with the square-foot area of each polygon, geoprocessing steps can be applied to calculate current and possible urban forest canopy cover for the entire City and for each Aldermanic district. The ash species were integrated into the decision making process to improve the targeted inspections, outreach efforts, urban forest mitigation and public policy making.

Conclusions

This project applied advanced geospatial technology, including high-resolution remotely sensed hyperspectral imagery and lidar data, followed by GIS analytical tools, to geospatially map the location and condition of ash species in the project area. A geospatially mapped host inventory represents the frontier for urban and rural forest management and constitutes a significant new tool needed for improved species mapping, risk assessment, forest health monitoring, early, rapid detection and management of invasive species such as the emerald ash borer.

Hyperspectral Imagery along with a short "ground-truth" field effort to obtain local sample points, was used to successfully identify and map ash trees in the Milwaukee project area. Additionally, this methodology could be easily replicated to develop similar accurate species maps and establish or improve risk maps for other major forest species such as beech (beech bark disease), hemlock (hemlock woolly adelgid) and oak (oak wilt) in remote areas that are inaccessible or difficult to survey using conventional ground sampling methods. Moreover, information from this study could be extrapolated to other regions of the Great Lake states through the National Risk Mapping Project.

High-resolution remotely sensed hyperspectral imagery provides the foundation for new invasive species best management practices. The ability to overlay an orthorectified mosaic species map with 80 percent or greater accuracy on an existing GIS parcel map represents a powerful new application for invasive species detection and response planning that would permit state and local survey personnel to target property owners with high ash concentrations for EAB inspections, monitoring, control, and dissemination of outreach materials. A geospatial ash inventory also permits forest managers to more accurately predict EAB movement. Increasing public awareness in these areas gets more eyes on the ground to identify a possible new infestation and also increases communication with property owners.

It proved critically important to collect numerous field spectra that were both spatially distributed throughout the project area and diverse from the standpoint of species, size, tree condition, and understory composition.

Acknowledgements

We would like to thank David Sivyer, Forestry Services Manager for the city of Milwaukee, for his vision, insight and close participation in this project. David Sivyer will be available on the RFP Mapping LLC website (www.rfpmappingllc.com) in a video interview regarding this project.

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