Operational Use of Hyperspectral Imagery for Forest Health Mapping

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ABSTRACT

Hyperspectral remote sensing imagery has been used to map foliar chemistry (N and Ca), forest productivity, species, and tree health at the landscape scale (25,000 acres to 840,000 acres). Most of this work has been accomplished by research teams using sensors and techniques that are not generally available for use by forest land managers. Recently, hyperspectral remote sensing imagery has become commercially available, making this technology more accessible. However, the techniques for processing this imagery and producing usable maps are complicated and still relatively new. This paper will provide information and guidelines to help forest land managers understand, contract for, and utilize hyperspectral remote sensing imagery to produce landscape scale maps of eastern hemlock health.

KEYWORDS

Remote sensing, hyperspectral, species mapping, hemlock health.

INTRODUCTION

The spread of the hemlock woolly adelgid (HWA, *Adelges tsugae* Annand) across the northeastern United States continues to threaten the eastern hemlock (*Tsuga canadensis* Carriere) resource. The potential loss of eastern hemlock from the forest ecosystem forces land managers to consider a wide array of possible treatment and management options. In order for land management agencies to begin to prioritize and design a focused management plan in response to HWA infestation, it is necessary to efficiently identify the location and health status of the eastern hemlock resource.

Currently, rough species type maps are created using aerial photography, aerial sketch maps, and on the ground surveys. In order to track hemlock health and HWA infestation field surveys are required and detection is limited to sampled plots. Existing remote sensing techniques using broad-band remote sensing imagery are limited to identifying trees only in severe states of decline. Such survey techniques cannot easily identify incipient infestation or early health problems.

Remote sensing technology has been available for landscape scale mapping of forest ecosystems for several decades. The primary users of this technology have typically been

researchers studying ecosystem dynamics at a landscape scale. Hyperspectral remote sensing imagery has been used to map foliar chemistry (N and Ca), forest productivity, species, and tree health at the landscape scale (25,000 acres to 840,000 acres)(Smith et al. 2002, Ollinger et al. 2002, Martin and Aber 1997, Pontius et al.In press-a and -b). Most of this work has been accomplished by research teams using sensors and techniques that are not generally available, for use by forest land managers. Recently, hyperspectral remote sensing imagery has become commercially available making this technology more accessible to forest land managers. However the techniques for processing this imagery and producing usable maps are complicated and still relatively new. This paper will provide information and guidelines to help forest land managers understand, contract for, and utilize hyperspectral remote sensing imagery to produce landscape scale maps of hemlock health.

USEFUL TERMS

1. Spatial Resolution: Spatial resolution is most often expressed in meters and refers to the area on the ground represented by a single image pixel. For example, a spatial resolution of 1 meter means that a single pixel will contain data from a 1 m by 1 m area on the ground. An image taken at 1 meter resolution is sufficient to show individual tree crowns in a forest. A spatial resolution of 20 meters will contain less detail and is appropriate for gaining stand-level information. For airborne instruments, spatial resolution is largely dependent upon the altitude at which the instrument is flown.

2. Spectral Resolution: Number and spectral width (in nanometers) of the bands of reflected light that can be recorded by the sensor. Many narrow bands covering a broad range of the spectrum are characteristic of hyperspectral instruments. The spectral resolution needed will depend on the questions to be answered. For example, identifying areas of severe defoliation will require significantly fewer bands than picking up pre-visual decline symptoms in newly infested stands.

3. Geo-registration: Geographic registration or geographic rectification is the spatial referencing of an image to a geographic coordinate system (e.g., latitude/longitude, UTM, State Plane). Once the image data is collected, it is important to be able to link each pixel in the image to the location it came from on the ground. The accuracy of geo-registration has a direct bearing on the usefulness of the final maps and the accuracy of ground truth input and validation.

WHAT IS HYPERSPECTRAL IMAGERY?

Hyperspectral remote sensing imagery is characterized by the large number of narrow bands of reflectance data collected across a broad range of the electromagnetic spectrum. Figure 1 shows a typical spectral signature from a vegetated pixel. NASA's hyperspectral Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) instrument collects data from 400 to 2400 nm. Commercial vendors typically utilize hyperspectral sensors that collect data from 400 to 1000 nm, although there are some full-range (~400-2500 nm) instruments available. By contrast, Landsat TM is classified as a multi-spectral instrument because it collects data in 6 broad bands of reflected light.

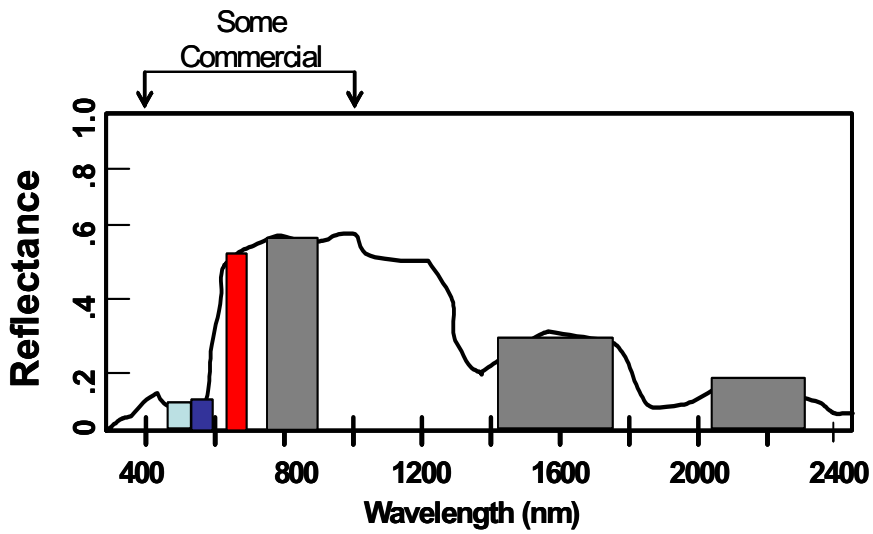

Figure 1. Typical spectral signature taken from a vegetated pixel. The AVIRIS instrument collects information from 400 to 2400 nm. Landsat TM collects information from the six broad regions designated by the shaded rectangles. Some commercial hyperspectral instruments collect data from 400 to 1000 nm.

The usefulness of each type of imagery is dependent on the information that is required for management decisions. For example, in order to map foliar N or Ca, the full spectral range shown in Figure 1 is necessary, including wavelengths across the near-infrared spectrum. However, hyperspectral data from 400 to 1000 nm may be sufficient for mapping hemlock health and distinguishing between different tree species (see Pontius et al. in this proceedings). Multi-spectral Landsat TM data has been shown to be capable of mapping hemlock health in broader categories and at a larger spatial scale (Royle and Lathrop 1997).

In order to create a usable map from hyperspectral imagery, there are several image processing steps that need to be completed. These steps are analogous to taking an aerial photograph, developing the film, having someone interpret the photo, and having a map made of species, wetlands, defoliation, etc., based on that interpretation. Figure 2 diagrams the process that is necessary to create a usable map of hemlock health from hyperspectral imagery.

WHAT CAN HYPERSPECTRAL REMOTE SENSING IMAGERY DO FOR YOU?

The benefit of hyperspectral data over traditional detection and monitoring techniques is the ability to detect minute changes in forest condition such as reductions in photosynthetic activity and chlorophyll content. This type of information is most useful in determining the very *early* signs of stress —stress that may not be visible on the ground or in aerial photography. For mature stands of hemlock where infestations are hard to detect, this may be the best way to track the spread of HWA and to target management activities where they have the best chance of success.

Hyperspectral remote sensing imagery can provide detailed information about the location and health of the hemlock resource with a high degree of accuracy. In addition, changes over time can be tracked using imagery from multiple years. Information of this nature can be used to provide focus for more intensive field surveys or activities. For example, instead of

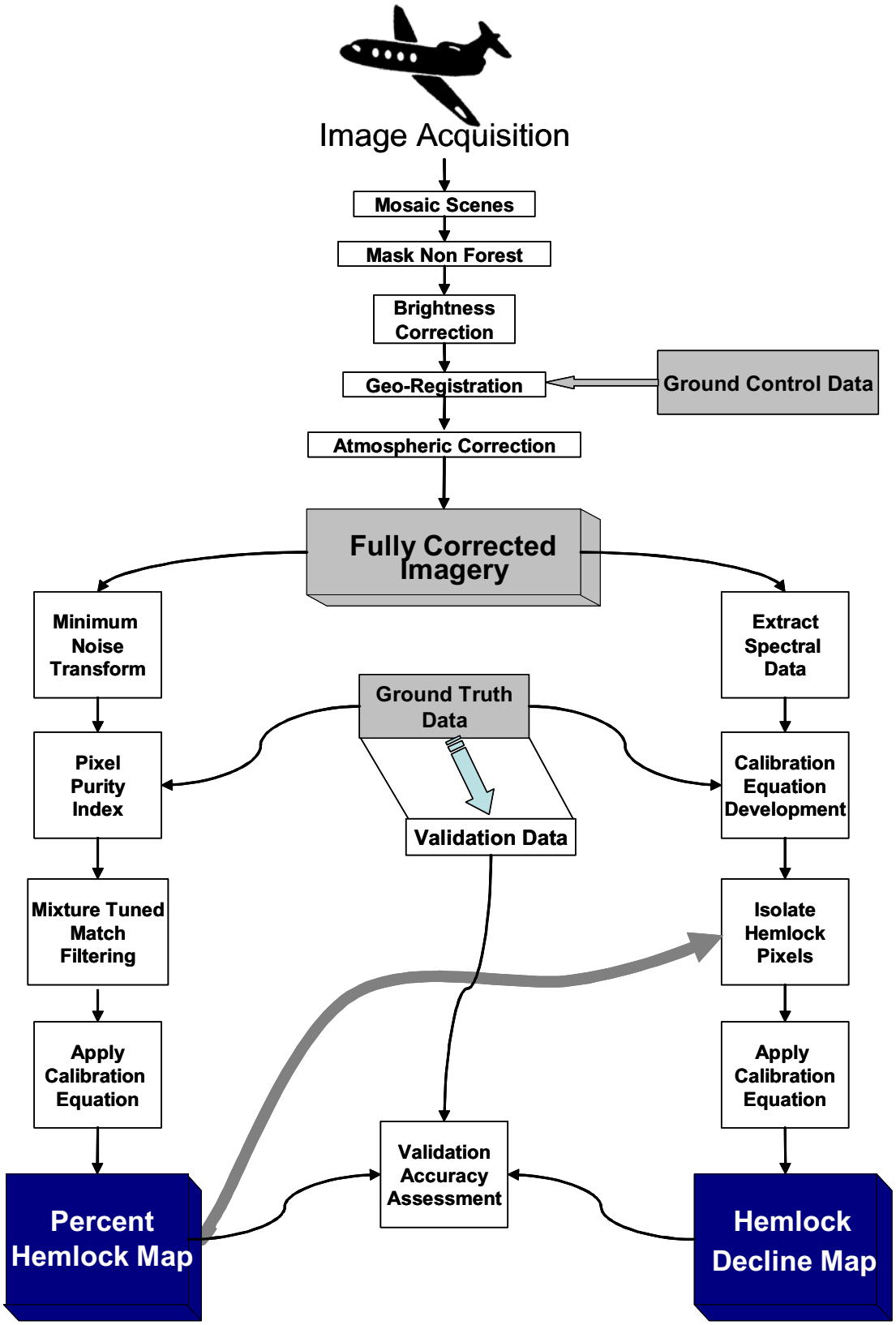

Figure 2. Flow chart of the image-processing steps typically required to derive useful data from hyperspectral imagery.

using field crews to conduct a field plot survey over large areas of the landscape to detect any new HWA infestation, remote sensing technology could be used to identify areas that appear to be unhealthy. Field crews could then be sent to areas identified as unhealthy to determine whether the source of the stress is HWA infestation.

The success of bio-control efforts is also dependent on identifying areas of moderate infestation, where trees are still relatively healthy. Continuous coverages of hemlock health would facilitate the location of appropriate release sites for predatory insects. Other remediation efforts, such as pesticide application are also dependent on locating infested areas with moderately healthy trees. Being able to provide landscape scale information to these management activities should improve their success rates.

IS HYPERSPECTRAL IMAGERY RIGHT FOR YOU?

The use of commercial use of hyperspectral imagery by forest land managers is new, and image acquisition and processing can be quite complicated and expensive. For these reasons, it is advisable to consider the management decisions you are facing in the context of whether the maps produced from hyperspectral imagery will provide new information, more detailed information, and/or, unique information about the landscape you are managing. In some cases you may find that existing methods and technologies are more efficient and/or cost effective. For example, if you are interested only in areas of severe hemlock decline, then Landsat TM data, aerial sketchmapping, and aerial photo-interpretation may be more cost effective options. However, if your management strategy depends upon early detection of decline and accurate mapping of the hemlock resource, then data products derived from hyperspectral imagery may be preferable.

WHERE CAN I GET HYPERSPECTRAL IMAGERY?

Hyperspectral data can be obtained from a number of commercial vendors (Table 1). It is important to note that the data products provided by these vendors will vary. In some cases, a vendor may provide final data products, such as maps of species or stand/tree health, whereas in other cases, the data product may be image data of surface reflectance in a varying number of spectral bands, covering a varying spectral range; in the latter case, it will be necessary to transform that spectral data into the data product required for your management decisions. Land managers may choose to transform spectral data into these final products in-house by applying analysis techniques and algorithms to the imagery or to contract with a third party to generate these products.

Table 1 includes some key variables that can help evaluate whether the instrument is suitable for your needs. The name of the actual instrument a vendor uses is important because different vendors may use the same instrument to produce their image data. The spectral range and resolution are important in determining the suitability of data in generating different products: the narrower the spectral resolution, the more refined predictions of forest health and species mapping will be. To date, the identification of early decline symptoms has been accomplished with up to 10-nm resolution spectra across the visible and near infrared wavelengths (400-800 nm). The location of the company may have a bearing on cost as it can be expensive to ferry the instrument long distances, although this may be mitigated somewhat if the company has other jobs in your area.

Table 1. List of potential sources of hyperspectral imagery. All except AVIRIS are currently commercially available.

Vendor	Instrument	Spectral Range (nm)	Spectral Resolution (nm)	No. of Bands	Platform	Location	Website
NASA	**AVIRIS**	**400 to 2400**	**10**	**224**	**Fixed wing**	**USA**	**http://aviris.jps.nasa.gov**
Helicopter Applicators Inc.	AISA Eagle 1K	400 to 1000	2.9	272	Helicopter	MD	www.helicopterapplicators.com
Flight Landata	HDHIS	446.5 to 906	2.5	240	Fixed wing	MA	www.flidata.com
Earth Search Sciences Inc.	PROBE-1	440 to 2400	14	128	Fixed wing	MT	www.earthsearch.com
Hyvista Corporation	HyMap	400 to 2500	15	126	Fixed wing	Australia	www.hyvista.com
SpecTIR	HyperSpecTIR	450 to 2450	12	227	Fixed wing	NV	www.spectir.com
Galileo Group Inc.	AISA+	400 to 1000	2.9	244	Helicopter/ fixed wing	FL	www.galileo-gp.com
Galileo Group Inc.	AISA Hawk	1000 to 2400	8	256	Helicopter/ fixed wing	FL	www.galileo-gp.com
ITRES	CASI 2	400 to 1000	1.9	288	Fixed wing	CO	www.itres.com

SPATIAL RESOLUTION

Imagery collected from an airborne platform can have variable spatial resolution. Flying closer to the ground will yield a more detailed image, sometimes reaching resolutions of less than 1 meter.

Careful consideration should be given to the level of detail that is required to answer your specific management question. It may not always be better to have a higher level of detail in your image: high spatial resolution images can be more expensive to collect because a smaller area on the ground is covered with each pass of the instrument, and so require more passes (and expense) to capture the area of interest. In addition, the data collected can be more difficult and time-consuming to process not only because of increased data dimensionality, but also because of the increased pixel variation (e.g., individual pixels that capture gaps in the canopy, variation in canopy structure, etc).

The size of the area to be mapped will also have a bearing on the level of detail necessary. For example, if you are mapping 100,000 acres, you may not need or want information for every tree (which is what 1-2 meter spatial resolution will yield): a map created with 20-meter spatial resolution will be sufficient for assessment of tree health and species abundance over large areas of the landscape. On the other hand if you are collecting imagery from urban areas where information on individual trees is essential, highly detailed spatial data (e.g., 1- to 4-m resolution) are necessary to accurately map vegetated and non-vegetated areas.

CONTRACTING FOR HYPERSPECTRAL IMAGE ACQUISITION AND PROCESSING.

There are several items that you may need to provide a vendor. These vary with the data product provided by the vendor, and include the following:

1. Boundary map
   A map of the area that you want flown. The map should be provided to the vendor's specifications. Some vendors require an Arc shapefile while others may only need the coordinates of the corners of the area to be flown.
2. Ground reference data
   Any hyperspectral imagery should have a set of ground truth data as input for the creation of predicted health and species mapping layers. This allows the image processor to train on areas of known infestation, health, and species composition and is necessary in order to maximize the utility of the imagery. In order to collect accurate ground reference data, you or the vendor will need a high-precision GPS unit capable of 1- to 2-meter accuracy

   a. Calibration and validation plot data (60 plots per image)

      Calibration and validation data are field plot measurements collected for species health or abundance. The plots should be spread evenly across the area to be flown. They should cover the full range of health or species abundance found in the area. The data collection should take place concurrent with the image acquisition in order to ensure identical conditions.

      If a vendor provides image data that needs to be processed into a final product, you must collect calibration and validation data. For example, forty plots could

be used to calibrate the imagery during the processing phase (e.g., transform the hyperspectral data into the final product) while an additional 20 plots would be used for validating the final product. We recommend this number of plots to ensure the creation of robust prediction equations.

If a vendor provides a final data product, such as species maps or health assessment maps, you may still need to provide the vendor with plot-level data for processing the imagery, as well as for reporting an estimate of accuracy for the final product (validation).

b. Ground control points (50 per image)

These plots are used to geographically register the image so it is possible to relate data from a point on the image to the same point on the ground. If the vendor does not collect ground control data, you will need to provide it yourself. Ground control points are field targets, such as road intersections that can be easily located on the image. For high spatial resolution imagery, isolated tree canopies may be used, while lower spatial resolution imagery would be limited to large road intersections, buildings, or cover type changes. A precise location on the ground is obtained using a high precision GPS unit (1-2 meter accuracy) and can be linked to pixels in image processing and GIS software programs. Fifty plots are often sufficient, while for some images, more or fewer plots are required. To ensure accurately geo-referenced data, these targets should be evenly distributed throughout the geographic extent of the image.

Alternatively, ground control points can be obtained through the use of a geo–registered digital ortho quad (DOQ) maps of your area from the United States Geological Survey. These can be used to extract latitude and longitude for points on the ground that corresponds to points visible in the image. Although easier, this method will yield less accurate results because there is some inherent error associated with the DOQ locational data. Ideally, ground control points obtained in the field would be used in conjunction with registration to DOQ imagery to provide the highest level of accuracy across an entire image.

3. Image processing and/or GIS software

Whether you will be processing the hyperspectral image data or receiving a final data product, you will likely need to be familiar with image processing and/or geographic information systems (GIS) software. This will facilitate the viewing and use of the final product.

In order to protect both the land-manager and vendor, a detailed contract should be developed. In developing this contract the following items be considered:

1. Complete image data coverage of the specified area
2. Spatial resolution requirements
3. Image data pre-processing

- All airborne image data collection is influenced by the atmospheric conditions at the time of flight. It is therefore necessary to convert imagery to reflectance using an atmospheric correction. Multiple programs currently exist (e.g., ACORN and ATREM) that are capable of transforming calibrated at-sensor radiance data to reflectance with minimal inputs, such as date and time of flight, altitude, humidity, etc.
- Depending on the sensor, and resolution, other pre-processing steps may be necessary, such as a view angle correction for scanning spectrometers or shadow removal for high spatial resolution imagery (Figure 2).

4. Documentation of spectral and radiometric instrument calibration procedures and results
   - This ensures that the instrument is being maintained properly and the data obtained from these procedures can help with image processing.

5. Image collection to meet following requirements:
   - Close to solar noon (i.e. ± 2 hours)
   - Collection under cloudless conditions is optimal. Given that portions of the image covered by clouds and their shadows are unusable, you should negotiate acceptable conditions in the contract.

6. Image geo-registration negotiated with vendor
   - At a minimum, a vendor should provide you with imagery that has had inertial navigation system (INS) correction. This corrects for the flight variables, such as roll, pitch and yaw, and must be performed for the imagery to be in a useable form. While this INS correction creates an image similar to an aerial photo, it does not assign geographic coordinates to the imagery: this requires a full geo-registration, which is offered by some vendors, or can be completed in-house. In areas of severe terrain, an orthorectification may also be required to maximize the accuracy or registration. If a vendor is to provide full geo-registration, the expected accuracy should be stated in the contract. Typically one can expect registration accuracy to within 2-3 pixels.

7. Image format
   - The format of the product delivered to you (whether reflectance data or a final prediction coverage) should be negotiated with vendor and match your in-house data-handling capabilities.

8. Final product with at least 80% accuracy
   - If the vendor is to provide a final prediction coverage to you, comparisons to your validation ground truth data should meet some specified accuracy level. It is not uncommon for hyperspectral sensors to predict health ratings and species classification with greater than 80% accuracy.

CONCLUSION

Hyperspectral remote sensing imagery is commercially available and has proven applicability for forest land managers who are making management decisions based upon the location and health of the hemlock resource. However, acquiring and processing this imagery is complicated, requires a high level of technical expertise, and can be expensive. Issues to consider before contracting for hyperspectral imagery include the added value of the expected maps, the level of spatial detail required, and the feasibility of utilizing digital mapping information. Careful attention needs to be given to insuring the spatial and informational accuracy of the final maps. Finally, it should be noted that even though remote sensing technology can produce detailed information for large contiguous areas of the landscape it does not eliminate the need for collecting field-based plot data.

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