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# Examining pine spectral separability using hyperspectral data from an airborne sensor: An extension of field-based results

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Three southern USA forestry species, loblolly pine (*Pinus taeda*), Virginia pine (*Pinus virginiana*), and shortleaf pine (*Pinus echinata*), were previously shown to be spectrally separable (83% accuracy) using data from a full-range spectroradiometer (400–2500 nm) acquired above tree canopies. This study focused on whether these same species are also separable using hyperspectral data acquired using the airborne visible/infrared imaging spectrometer (AVIRIS). Stepwise discriminant techniques were used to reduce data dimensionality to a maximum of 10 spectral bands, followed by discriminant techniques to measure separability. Discriminatory variables were largely located in the visible and near-infrared regions of the spectrum. Cross-validation accuracies ranged from 65% (1 pixel radiance data) to as high as 85% (3 × 3 pixel radiance data), indicating that these species have strong potential to be classified accurately using hyperspectral data from air- or space-borne sensors.

*Keywords*: AVIRIS; spectrometer; forestry; hyperspectral data; classification

## 1. Introduction

Accurate species discrimination is important for forest inventory, pest and environmental stress management, and assessing per-species carbon sequestration. Forest type classifications have traditionally used multispectral data (e.g. Franklin 1994), while hyperspectral data have been used to discriminate between deciduous forest species accurately (Martin *et al.* 1998). However, the use of hyperspectral data for conifer species recognition has not been as extensively explored, with only three previous studies bearing explicit mention.

Gong *et al.* (1997) used an artificial neural network and discriminant analysis with spectroradiometer data (250–1050 nm) to spectrally differentiate (91% accuracy) six coniferous species (sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), white fir (*Abies concolor*), Douglas fir (*Pseudotsuga menziesii*), incense cedar (*Calocedrus decurrens*), and giant sequoia (*Sequoiadendron giganteum*)) and one hardwood species, (California black oak (*Quercus keloggii*)) at the canopy level. Fung *et al.* (1999) used a spectroradiometer (210–1050 nm) to analyse species separability by measuring laboratory, branch-level reflectance spectra during all four seasons. Species included slash pine (*Pinus elliottii*), bald cypress (*Taxodium*

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*distichum*), tallowtree (*Sapium sebiferum*), punktree (*Melaleuca quinquenervia*), and bottletree (*Firmiana simplex*). The first and second derivatives of the spectra were used in a linear discriminant analysis, and the accuracies varied from 56–91%. Van Aardt and Wynne (2001) investigated the inherent canopy spectral separability among three southern pine species, namely loblolly pine (*Pinus taeda*), Virginia pine (*Pinus virginiana*), and shortleaf pine (*Pinus echinata*), using high spectral resolution spectroradiometer reflectance data (350–2500 nm). Discriminant techniques were used to reduce data dimensionality and test spectral separability among species. Cross-validation accuracies ranged between 62% (second difference of raw relative reflectance) and 84% (second difference of smoothed relative reflectance).

Tree species separability studies using data from airborne imaging spectrometers, while scarce, do exist. Martin *et al.* (1998) classified 11 different forest cover types at the stand-level, including red maple (*Acer rubrum*), red oak (*Quercus rubra*), white pine (*Pinus strobus*), red pine (*Pinus resinosa*), Norway spruce (*Picea abies*), and pure hemlock (*Tsuga canadensis*), as well as mixtures thereof, using first difference airborne AVIRIS reflectance data (75% accuracy). Lawrence *et al.* (1993) found distinct qualitative differences between coniferous and deciduous vegetation using AVIRIS imagery acquired over hemlock-spruce-fir (*Tsuga* spp., *Picea* spp., and *Abies* spp.), hemlock-hardwood (*Tsuga* spp. and hardwoods), and aspen-birch (*Populus* spp. and *Betula* spp.) mixed stands. Thenkabail *et al.* (2004) used Hyperion data to classify nine land use-land cover classes at the plot-level (1 ha), thereby reducing mixed-pixel effects. Cover classes ranged from slash-and-burn farm to undisturbed primary forests, in tropical rain forests (Cameroon). Stepwise discriminant analysis yielded an accuracy of 96% using 23 bands, with a distinct increase in classification accuracy as the number of bands increased. Clark *et al.* (in press) investigated species-level separability of seven tropical rain forest species, using laboratory (leaf-level) and airborne (canopy-level) hyperspectral data. Linear discriminant analysis at the leaf-scale (laboratory) had an overall accuracy of 100%, albeit based on 40 wavelengths. Maximum likelihood classification at the pixel-scale resulted in an 88% overall accuracy, but once again as many as 60 wavelengths were used.

No previous study has examined the degree to which commercial pine species in the southeastern USA can be identified using airborne hyperspectral data. Conclusive evidence of pine spectral separability is needed, given the inherently similar spectral nature of pine species and the need to avoid over-parameterization in discriminant techniques (van Aardt and Wynne 2001), the economic importance of these species (University of Georgia 2000), and the ecological niche they fulfil in forest ecosystems (Society of American Foresters 1980).

The goal of this study was to determine whether loblolly pine (*Pinus taeda*), Virginia pine (*Pinus virginiana*), and shortleaf pine (*Pinus echinata*) are as separable using hyperspectral data acquired from an airborne sensor (AVIRIS) as they were using field spectroradiometer data (van Aardt and Wynne 2001).

## 2. Methods

The study area is located in Appomattox Buckingham State Forest, Virginia, USA (78°40′30″ W, 37°25′9″ N). This Virginia piedmont region consists of various pine, upland hardwood, and mixed stands. Four AVIRIS 224-band, low-altitude flight lines were acquired in the winter of 1999 and ranged from 400–2500 nm (10 nm spectral resolution) with 3.4 m spatial resolution. The non-atmospherically corrected

Table 1. Data sets used for stepwise and discriminant analysis, as well as the α-level used and wavelengths selected by stepwise discriminant analysis.

| Data set | | α-level | Wavelengths |
|---|---|---|---|
| Radiance data: 1 pixel neighbourhood | Raw data | 0.03 | 547, 557, 596, 692, 1842 nm |
| | First difference | 0.01 | 527, 547, 557, 566, 711, 1115, 1247, 1534 nm |
| | Second difference | 0.015 | 527, 537, 547, 557, 663, 701, 1087, 1209, 2151 nm |
| Radiance data: 3 × 3 pixel neighbourhood | Raw data | 0.01 | 439, 488, 527, 547, 566, 692, 946, 1190, 1255, 1842 nm |
| | First difference | 0.01 | 399, 508, 537, 576, 663, 711, 1172, 1237, 1375 nm |
| | Second difference | 0.01 | 399, 537, 547, 557, 692, 816, 974, 1365, 1474, 1803 nm |

AVIRIS data were geometrically and radiometrically (radiance: $\mu$Wcm$^{-2}$nm$^{-1}$sr$^{-1}$) corrected by the Jet Propulsion Laboratory (JPL; Pasadena, California, USA). Radiometric calibration is accurate to within 7% of absolute values (JPL 2005). Radiance data (table 1) were used since the study focused on relative spectral separability as opposed to multi-temporal applications, thereby obviating the need for atmospherically corrected imagery and reducing image errors introduced by atmospheric modeling. A BRDF correction also was deemed unnecessary, given the short delay (1 hour and 6 minutes) between the first (11h 34 local time) and last (12h 40 local time) flight line acquisition. The three flight lines used for this study were registered (8–12 control points per flight line) to an existing 0.5 m orthophoto of the area. Resampling resulted in root mean square errors (RMSE) ranging between 0.23 and 0.24 pixels. Homogeneous spectral samples for 89 loblolly, 45 shortleaf, and 65 Virginia pine locations were extracted from the AVIRIS imagery using 1-pixel and 3 × 3-pixel windows for two separate analyses. The extracted spectral samples were located in the AVIRIS imagery using coordinates from differentially corrected GPS locations collected in-field, each at a location homogenous with respect to overstory species within a 15 m radius.

Reduction of data dimensionality was done using stepwise discriminant analysis, which selects spectral bands that minimize within-statistical-group variance while maximizing the between-group variance for a given α-level (table 1). The α-levels were varied to select a maximum of 10 spectral bands, based on the number of variables used in previous studies (Martin *et al.* 1998, van Aardt and Wynne 2001). Spectral bands chosen by the stepwise discriminant analysis were used as input to linear discriminant and canonical discriminant procedures to test between- and within-species separability. These techniques serve to develop linear discriminant functions and define canonical variables for visual separation, respectively. Discrimination accuracy was assessed through cross-validation within the discriminant procedure.

## 3. Results

Results from the stepwise discriminant analysis are shown in table 1, while the cross-validation results are shown in table 2. Figures 1 and 2 show canonical discriminant plots for canonical variables one and two for the most accurate and least accurate data sets, namely 3 × 3 and 1-pixel radiance data, respectively. The separability among species, or lack thereof, can be seen when comparing the two canonical plots.

Table 2. Cross-validation results from discriminant analysis.

| Data set | | Accuracy | | | |
|---|---|---|---|---|---|
| | | Loblolly | Shortleaf | Virginia | Overall |
| 1 pixel neighbourhood | Radiance | 70% | 50% | 71% | *65%* |
| | Radiance: 1st difference | 76% | 71% | 82% | *77%* |
| | Radiance: 2nd difference | 72% | 65% | 77% | *72%* |
| 3 × 3 pixel neighbourhood | Radiance | 85% | 80% | 88% | *85%* |
| | Radiance: 1st difference | 81% | 69% | 83% | *79%* |
| | Radiance: 2nd difference | 82% | 69% | 78% | *78%* |

## 4. Discussion

Selected stepwise wavelengths indicated that visible and near-infrared regions were again important in the spectral separation of the three pine species, as shown by van Aardt and Wynne (2001). A comparison of wavelengths found to be discriminatory in the two studies is shown in table 3. Analysis of the airborne AVIRIS data resulted in more variables across the entire range (especially near-infrared), with the exception of the blue region. This might be due to the initial study containing only pure canopy spectra, while the background noise (e.g. litter, stem, branch, and shadow effects) in this study necessitated the use of a wider range of wavelengths for discrimination.

The highest accuracy (85%) was associated with non-differenced radiance data, although accuracies for differenced data also showed promise (72%–79%). This was

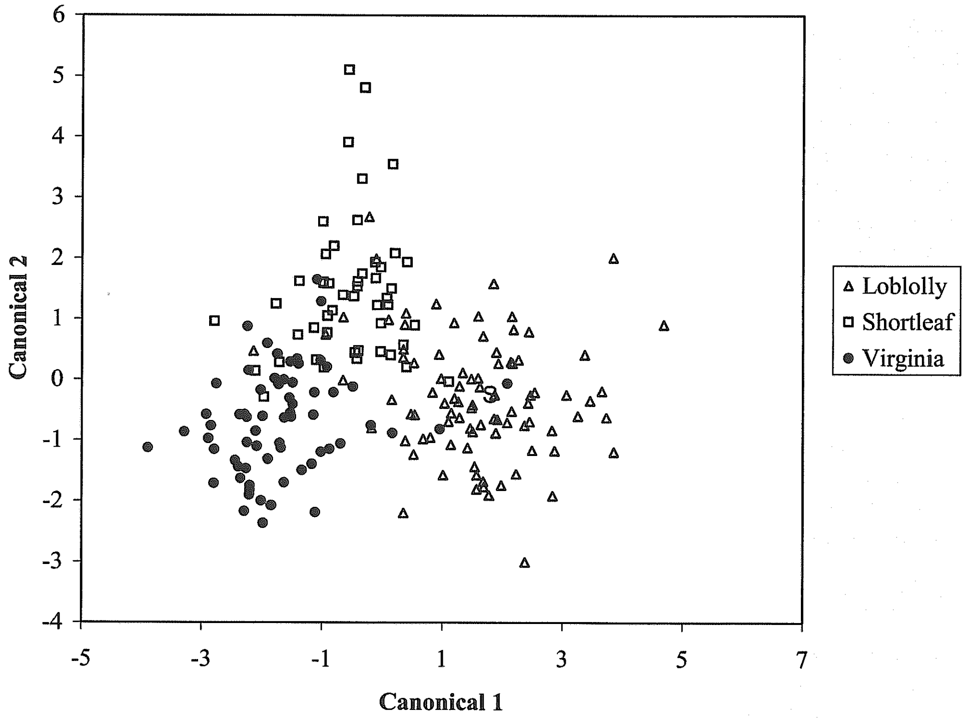

Figure 1. Canonical variable plot for the best performing data set (85% accuracy): 3 × 3 radiance data; 10 variables.

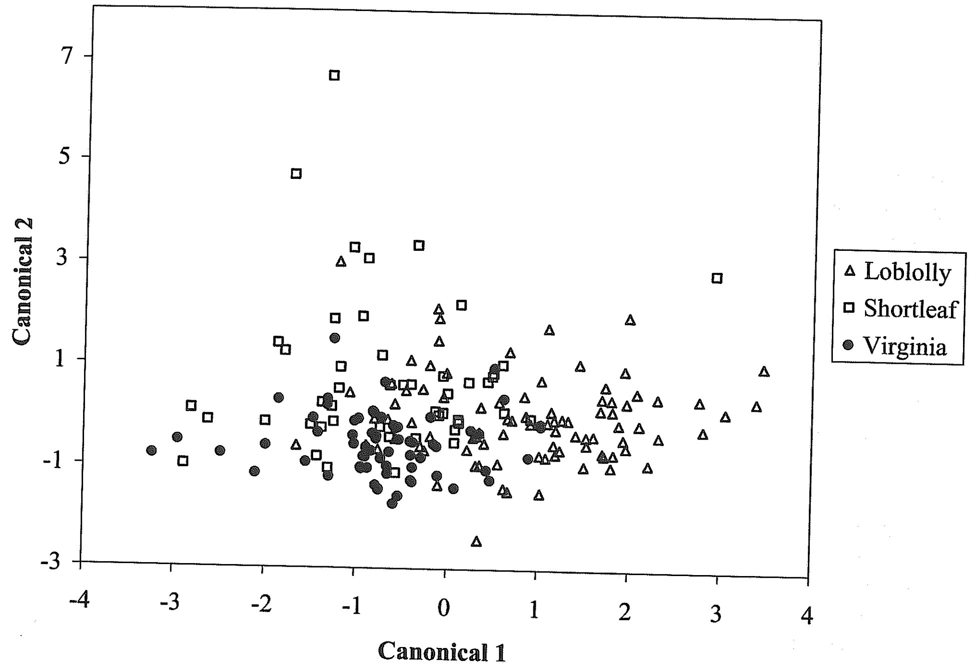

Figure 2. Canonical variable plot for the worst performing data set (65% accuracy): 1-pixel radiance data; 5 variables.

contradictory to results obtained by Gong *et al.* (1993) (neural networks) and Martin *et al.* (1998), who highlighted the importance of differenced data. Lower accuracies for 1-pixel analysis were attributed to the degree of spatial uncertainty (misregistration error or locational uncertainty) inherent in geographical data, compounded by the high spatial resolution of the AVIRIS data. This result could imply that accuracies would decrease as forest species heterogeneity increases. Averaged data for 3 × 3 neighbourhood sample selection reduced effects of positional inaccuracies. Such a neighbourhood selection also took average spectral properties of grouped trees into account, including components other than strict foliage matter. It should be noted that individual trees could be classified using this approach, given high enough spatial resolution and appropriate machine vision techniques.

Table 3. Comparison of discriminatory wavelengths to best spectrally separate loblolly, shortleaf, and Virginia pine for the van Aardt and Wynne (2001) and current study.

| *van Aardt and Wynne (2001) – discriminatory wavelengths*; 83% accuracy (AVIRIS simulation data; radiance) | *Current study – discriminatory wavelengths*; 85% accuracy (AVIRIS data; 3 × 3 pixel radiance data) |
|---|---|
| *<Blue*: 360 nm<br>*Blue*: 410 nm, 420 nm, 440 nm, 490 nm<br>*Red & Near-Infrared*: 650 nm, 1340 nm | *<Blue*: None<br>*Blue*: 439 nm, 488 nm<br>*Green*: 527 nm, 547 nm, 566 nm<br>*Red & Near-infrared*: 692 nm, 946 nm, 1190 nm, 1255 nm<br>*Short-wave-infrared*: 1842 nm |

## 5. Conclusions

Accurate spectral discrimination of pine species can be extended from field-based measurements to airborne hyperspectral data. This was confirmed by accuracies as high as 85% when 3.4 m AVIRIS data were used. Stepwise discriminant techniques effectively reduced data dimensionality, while discriminant analysis resulted in accurate spectral species discrimination. Higher accuracies for 3 × 3 neighbourhood samples, as opposed to single pixel data, were attributed to more representative sampling and data smoothing in the first case. Classification of 3 × 3 neighbourhood raw radiance data was most accurate (85%). Discriminant wavelengths mainly were located in the visible and near-infrared spectral regions, indicating that a limited number of relatively short wavelength bands can be used for accurate species-based classification and inventory.

Future work could include determining the spectral separability of other coniferous species. Accurately classifying tree species will aid in efficient forest management, whether for commercial (e.g. inventory) or environmental (e.g. carbon sequestration) goals.

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