SPECTRAL REFLECTANCE OF FIVE HARDWOOD TREE SPECIES IN SOUTHERN INDIANA

Dale R. Weigel and J.C. Randolph[1]

Abstract.—The use of remote sensing to identify forest species has been ongoing since the launch of Landsat-1 using MSS imagery. The ability to separate hardwoods from conifers was accomplished by the 1980s. However, distinguishing individual hardwood species is more problematic due to similar spectral and phenological characteristics. With the launch of commercial satellites with 1-meter panchromatic and 4-meter multispectral resolution or better resolution the potential exists to distinguish individual tree crowns and thus tree species. We attempted to distinguish five hardwood tree species: American beech, black oak, sugar maple, yellow-poplar, and white oak. These five species occur commonly in southern Indiana. The spectral reflectance of single leaves from five trees of each of the five species, collected monthly from May to November, was determined using a LI-COR spectroradiometer and a specially designed spectroradiometer. We found no significant difference in the reflectance spectra of the leaves of these five species in the blue (0.45-0.52µ*m*), green (0.52-0.60 µ*m*), red (0.63-0.69 µ*m*), and near-infrared (0.76-0.85 µ*m*) wavelengths. While higher spatial resolution satellite imagery is now available, our research indicates that spectral resolution still is not sufficiently high to separate hardwood trees species.

INTRODUCTION

With the launch of Landsat-1 in 1972 there has been a continual and increasing interest in using remotely sensed images for forestry applications. Interest has ranged from differentiating the basic forest versus nonforest to the more complex species change over time. Landsat-1 was equipped with the Multispectral Scanner (MSS) with a pixel size of 79 m. Because of the large pixel size, it was not possible to distinguish individual tree species. The MSS was no longer included on Landsat-6 and later. The launch of Landsat-4 in 1982 included the Thematic Mapper (TM) with a pixel size of 30 m. The pixel size was still too large to enable separation of individual tree species.

While individual tree species could not be distinguished with MSS and TM data, forest types are distinguishable (Wolter et al. 1995); evergreen stands can be separated from deciduous stands especially if leaf-off imagery was obtained.

The launch of IKONOS by Space Imaging in 1999 marked the beginning of high-resolution commercially available satellite imagery. IKONOS imagery was available in 1-m panchromatic and 4-m multispectral resolution. Spectral resolution was similar to Landsat with blue (0.445-0.516µm), green (0.506-0.595µm), red (0.632-0.698µm), and near-IR (0.757-0.853µm) bands. Additional commercial satellites continue to be launched with ever increasing pixel resolution. GeoEye-1, launched in September 2008, had spatial resolution of 41-cm panchromatic and 1.65-cm multispectral. This increased spatial resolution provided the potential to distinguish individual tree canopies and thus the ability to identify individual tree species.

[1]Forester (DRW), U.S. Forest Service, Hoosier National Forest, 811 Constitution Avenue, Bedford, IN 47421; Professor (JCR), Indiana University, School of Public and Environmental Affairs. DRW is corresponding author: to contact, call (812) 276-4774 or email at dweigel@fs.fed.us.

The higher spatial resolution imagery provided the potential to distinguish individual trees species. Gougeon (1995, 2000) used a valley-following technique to delineate individual conifer tree crowns. This technique makes use of darker shaded pixels usually found between conifer trees in a stand. The darker shaded pixels are joined to form individual tree crowns. This work and that done by Wang et al. (2004) dealt with conifers, trees with easily defined crowns. However as Key et al. (2001) noted "deciduous forests appear to be a greater challenge."

Our objective was to determine whether, under controlled conditions, it is possible to distinguish from the spectral reflectance five hardwood tree species using pseudo-IKONOS images.

METHODS

Study Area

The study was conducted in 2007 on the Hardin Ridge Recreation Area (39°01'15" N, 86°27'25" W) of the Hoosier National Forest in southern Indiana (Fig. 1). The recreation area provided easy access to the open-grown tree canopies. The recreation area is in the Brown County Hills subsection of the Interior Low Plateau-Transition Hills section of the Central Interior Broadleaf Forest province (Cleland et al. 2007). The dominant forest type in the area is oak-hickory. The average annual precipitation is 43 inches spread evenly throughout the year. July has the highest average temperature, 76 °F, and January has the lowest average temperature, 27 °F.

Sampling

At each sampling date, one leaf was removed from five trees of each of five species: American beech (*Fagus grandifolia* Ehrh.), black oak (*Quercus velutina* Lam.), sugar maple (*Acer saccharum* Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), and white oak (*Quercus alba* L.). These species occur commonly in southern Indiana (Leatherberry 2003). The individual trees were located throughout the recreation area (Fig. 1).

Leaves were sampled throughout the growing season from leaf-out in the spring until color change and leaf-drop in the fall. The sample dates during 2007 were May 15 and 31, July 2 and 31, August 31, September 14 and 27, and October 12 and 31. The selected leaves were all-sun leaves; no shade leaves were collected. All leaves were collected and spectral measurements made between 9 a.m. and noon on each sample date. Each leaf was photographed to provide a visual reference.

Spectral Measurements

The lower right area of each leaf was placed in a LI-COR reflectance sphere (LI-COR, Inc, Lincoln, NE). Two spectroradiometers were used to measure leaf reflectance. A LI-COR LI-1800 portable spectroradiometer measured reflectance in 2 nm increments from 350 to 850 nm. Data were recorded on a Dell laptop computer using WIN1800 software from LI-COR. The second instrument was a custom designed Omni-Spec spectroradiometer that measured reflectance in 3.3 nm increments from 350 to 1000 nm and 6.3 nm increments from 1000 to 1650 nm. Those data were recorded on a Palm Pilot. Both datasets were then exported to Microsoft Excel.

Figure 1.—Study location and trees sampled at Hardin Ridge Recreation Area, Hoosier National Forest.

Data Analysis

Using Microsoft Excel, the spectral reflectance of each leaf in each of the four bands, blue (0.45-0.52µ*m*), green (0.52-0.60 µ*m*), red (0.63-0.69 µ*m*), and near-infrared (0.76-0.853 µ*m*), was averaged into one reflectance spectra for each band creating a pseudo-multispectral IKONOS image.

Statistical analysis was performed using SAS (SAS Institute Inc., 2007) statistical software. Analysis of variance (ANOVA) was conducted by date and by band for reflectance values of the five species. Means separation between species was performed using Scheffe's multiple-comparison procedure and Tukey's studentized range test (Day and Quinn 1989).

RESULTS AND DISCUSSION

The spectral reflectance values were obtained under very controlled conditions. The light was from one direction focused at the leaf held at the same specific angle for each leaf. These conditions are quite dissimilar from those encountered under natural conditions. Under natural conditions leaves are at varying angles to the sun; sunlight may be hitting the leaves at different angles due to aspect and slope position of the tree; and leaf position within the tree affects light reflectance. However, these controlled conditions test whether it is possible to separate the five individual tree species. If it is not possible under controlled laboratory conditions, it will also not be possible under natural conditions that increase reflectance variability.

No single testing date provided a separation of the five tree species. With the LI-COR equipment, the mid- and late-May dates provided the most separation with all bands except the green band providing some separation (Table 1). But the separation tended to be one species separate from one or two with the remaining species not differing from the other species. The custom designed Omni-Spec spectroradiometer sensor only provided separation in the near-IR band (Table 2). Again it was just one species separating from another with the three other species not differing from the two species.

Table 1.—Reflectance values of four multispectral bands by date and tree species using the LI-COR spectroradiometer. For a given date and within a column, values followed by the same letter are not significantly different using Tukey's studentized range test α = 0.05.

		Blue 0.45-0.52	Green 0.52-0.60	Red 0.63-0.69	Near-IR 0.76-0.853
	Species	μm			
May 31	A beech	0.0498ab	0.1029a	0.0506ab	0.4815ab
	B oak	0.0541a	0.0985a	0.0561a	0.4878ab
	S maple	0.0479b	0.0948a	0.0473b	0.4674b
	Y-poplar	0.0501ab	0.1183a	0.0510ab	0.5007a
	W oak	0.0485ab	0.0879a	0.0459b	0.4671b
July 2	A beech	0.0484a	0.0859a	0.0489a	0.4743b
	B oak	0.0522a	0.0926a	0.0530a	0.4822b
	S maple	0.0507a	0.1066a	0.0525a	0.4712b
	Y-poplar	0.0477a	0.1005a	0.0470a	0.5095a
	W oak	0.0512a	0.0881a	0.0476a	0.4721b
July 31	A beech	0.0490b	0.0876a	0.0496a	0.4796a
	B oak	0.0516ab	0.0908a	0.0520a	0.4805a
	S maple	0.0506ab	0.0954a	0.0501a	0.4764a
	Y-poplar	0.0497ab	0.1000a	0.0500a	0.4904a
	W oak	0.0539a	0.0966a	0.0545a	0.4699a
Aug 31	A beech	0.0499a	0.0922a	0.0512a	0.4836a
	B oak	0.0512a	0.0886a	0.0520a	0.4824a
	S maple	0.0525a	0.1075a	0.0536a	0.4761a
	Y-poplar	0.0517a	0.1083a	0.0547a	0.4971a
	W oak	0.0529a	0.0861a	0.0532a	0.4721a
Sept 14	A beech	0.0511a	0.0923ab	0.0525a	0.4867ab
	B oak	0.0509a	0.0882b	0.0519a	0.4831ab
	S maple	0.0532a	0.1106ab	0.0555a	0.4830ab
	Y-poplar	0.0539a	0.1166a	0.0583a	0.5072a
	W oak	0.0539a	0.0916ab	0.0552a	0.4672b
Sept 27	A beech	0.0513a	0.0949a	0.0533a	0.4895ab
	B oak	0.0547a	0.1047a	0.0571a	0.4973ab
	S maple	0.0551a	0.1191a	0.0594a	0.4810b
	Y-poplar	0.0563a	0.1295a	0.0602a	0.5135a
	W oak	0.0539a	0.0928a	0.0534a	0.4769b
Oct 12	A beech	0.0530a	0.1023a	0.0564a	0.4882ab
	B oak	0.0538a	0.0974a	0.0559a	0.4871ab
	S maple	0.0570a	0.1259a	0.0629a	0.4854ab
	Y-poplar	0.0538a	0.1333a	0.0604a	0.5083a
	W oak	0.0561a	0.0957a	0.0566a	0.4678b
Oct 31	A beech	0.0598a	0.1888a	0.1530a	0.4830a
	B oak	0.0589a	0.1261a	0.0680a	0.4960a
	S maple	0.0704a	0.1652a	0.1484a	0.4793a
	Y-poplar	0.0648a	0.2094a	0.1394a	0.5069a
	W oak	0.0689a	0.1333a	0.0761a	0.4920a

Table 2.—Reflectance values of four multispectral bands by date and tree species using the Omni-Spec spectroradiometer. For a given date and within a column, values followed by the same letter are not significantly different using Tukey's studentized range test α = 0.05.

		Blue 0.45-0.52	Green 0.52-0.60	Red 0.63-0.69	Near-IR 0.76-0.853
	Species		μm		
May 31	A beech	0.0821a	0.1172a	0.0743a	0.5108ab
	B oak	0.0857a	0.1192a	0.0797a	0.5192ab
	S maple	0.0802a	0.1145a	0.0712a	0.4985b
	Y-poplar	0.0814a	0.1383a	0.0776a	0.5289a
	W oak	0.0813a	0.1108a	0.0727a	0.4998b
July 2	A beech	0.0803a	0.1058a	0.0735a	0.5063b
	B oak	0.0838a	0.1131a	0.0798a	0.5145b
	S maple	0.0826a	0.1266a	0.0808a	0.5047b
	Y-poplar	0.0814a	0.1263a	0.0795a	0.5403a
	W oak	0.0826a	0.1075a	0.0709a	0.5019b
July 31	A beech	0.0815c	0.1071a	0.0735a	0.5110a
	B oak	0.0852ab	0.1125a	0.0772a	0.5184a
	S maple	0.0841abc	0.1169a	0.0751a	0.5100a
	Y-poplar	0.0827bc	0.1205a	0.0740a	0.5234a
	W oak	0.0868a	0.1162a	0.0784a	0.5018a
Aug 31	A beech	0.0814a	0.1141ab	0.0767a	0.5183a
	B oak	0.0821a	0.1093ab	0.0761a	0.5130a
	S maple	0.0833a	0.1288ab	0.0775a	0.5063a
	Y-poplar	0.0836a	0.1329a	0.0798a	0.5304a
	W oak	0.0824a	0.1053b	0.0750a	0.5052a
Sept 14	A beech	0.0820a	0.1126ab	0.0769a	0.5199ab
	B oak	0.0821a	0.1088a	0.0753a	0.5176ab
	S maple	0.0839a	0.1312ab	0.0799a	0.5136ab
	T-poplar	0.0843a	0.1377a	0.0812a	0.5367a
	W oak	0.0857a	0.1133ab	0.0788a	0.5009b
Sept 27	A beech	0.0858a	0.1212a	0.0826a	0.5346a
	B oak	0.0879a	0.1269a	0.0834a	0.5358a
	S maple	0.0873a	0.1390a	0.0854a	0.5195a
	Y-poplar	0.0886a	0.1503a	0.0881a	0.5408a
	W oak	0.0872a	0.1177a	0.0793a	0.5173a
Oct 12	A beech	0.0871a	0.1276a	0.0836a	0.5339a
	B oak	0.0866a	0.1186a	0.0807a	0.5251a
	S maple	0.0901a	0.1491a	0.0882a	0.5206a
	Y-poplar	0.0865a	0.1530a	0.0834a	0.5413a
	W oak	0.0905a	0.1204a	0.0831a	0.5179a
Oct 31	A beech	0.0948a	0.2112a	0.1824a	0.5244a
	B oak	0.0951a	0.1541a	0.0982a	0.5393a
	S maple	0.1077a	0.1930a	0.1865a	0.5154a
	Y-poplar	0.0995a	0.2261a	0.1660a	0.5436a
	W oak	0.0995a	0.1501a	0.0980a	0.5288a

Reflectance, measured by the LI-COR spectroradiometer, provided only species separation in the near-IR band from leaves collected in mid-October (Table 1). Yellow-poplar separated from white oak with the three remaining species not different from the yellow-poplar or white oak. The Omni-Spec spectroradiometer was unable to differentiate any species for the two dates in October (Table 2). With leaf senescence, fall would seem to be a time when species separation would be possible. Different species begin senescence at different periods, with yellow-poplar beginning the earliest.

With the LI-COR spectroradiometer, the near-IR band was the only band with consistent species separation in six of the nine dates (Table 1). Again it was yellow-poplar separating from other species. However, the Omni-Spec spectroradiometer did not perform as well. The blue band had one date with separation, July 31; green band two dates, August 31 and September 14; and the red band had no species differentiation (Table 2). The slightly wider spectral increments of the Omni-Spec instrument, when averaged to get a single mean for each band, may result in less discrimination of reflectance values.

CONCLUSION

Our pseudo-multispectral IKONOS imagery did not provide adequate spectral separation among the five hardwood species we examined. This result suggests that current multispectral imagery cannot be used to distinguish hardwood tree species in the Central Hardwood Region.

While leaves collected in mid- to late-May provided the best samples to differentiate species, this time period is a limited image-acquisition window. The optimum time of greatest spectral differences may vary each year depending on weather and its influence on leaf development and expansion. Summer dates, with full leaf expansion and a longer image-acquisition period, had poorer spectral separation among species. The October dates had minimal spectral separation. The October time period like the May period is a limited image acquisition window being influenced by the weather.

Continued research is planned using the hyperspectral data, discriminant analysis, and additional statistical techniques. Because this was just an initial look at the hyperspectral data this continued examination using more sophisticated statistical techniques might provide useful methods to discriminate between the five hardwood species.

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