Hyperspectral remote sensing of invasive plants: detecting lianas in Panama

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Summary  Invasive plant species with distinct spectral characteristics can be detected and mapped using hyperspectral remote sensors. Preliminary studies at the leaf level using a spectrometer may be used to identify differences in leaf optical properties between weedy and non-weedy species. Remote sensing of plant canopies, at the ground level, or using imagery from airborne or satellite-borne sensors, is more complex. Canopy reflectance is affected by additional factors including leaf angle distribution, leaf density, plant health, life stage, and mixed spectral signatures from multiple plant species, as well as background soil or litter. This paper briefly reviews the most recent research on identifying invasive plants with hyperspectral data at different scales and illustrates its use for detecting invasive lianas (woody vines) in a tropical dry forest of Panama.

Keywords  Canopy, hyperspectral data, invasive, leaf, liana, remote sensing, spectrometer.

INTRODUCTION  Invasive plant species have been proposed as a major threat to the integrity of ecological systems (Mooney and Cleland 2001). The spread of aggressive weedy species can have far-reaching consequences, including habitat degradation, reduced agricultural productivity and decreased biodiversity. Early detection of small populations increases the chance of eradication and reduces the cost of control (Lass et al. 2005). For established populations, monitoring their spread is necessary for developing management and control programs. Hyperspectral remote sensing is emerging as a promising option for timely, efficient detection and monitoring of invasive plant species.

Hyperspectral remote sensing technology has already proven to be a valuable tool for mapping distribution and infestation levels of invasive plants in agricultural systems, rangelands, and wetlands (Table 1). These sensors gather reflected light over numerous contiguous narrow wavebands in the electromagnetic spectrum (<5 nm in width), in contrast to multispectral sensors (e.g. aerial photography, LANDSAT), which provide data over fewer (3–7) broad-width wavebands. Hyperspectral data in the visible and near-infrared regions (400–2500 nm) allow the detection of subtle differences in vegetation spectra, holding much promise for the discrimination of species (i.e. weed vs. non-weed).

Prior to mapping invasive species using hyperspectral remotely sensed imagery, in situ studies at leaf and canopy scales can be useful to determine if there are significant differences between the spectral signatures of target and non-target species. Leaf-level hyperspectral measurements, gathered using a spectrometer, and complementary data on leaf traits (e.g. leaf surface morphology, pigment concentrations, leaf width, water content) provide an important starting point for understanding a species’ spectral signature. Canopy-level hyperspectral reflectance measurements may be measured just above the ground level, in situ, or from airborne or satellite-borne sensors. Studies at each scale offer insight into the spectral reflectance characteristics of invasive plants and the potential for mapping them, using remotely sensed imagery. The main objective of this paper is to briefly review the current status of hyperspectral remote sensing of invasive plants at leaf and canopy scales, and to provide a case study on detecting lianas (woody vines) in a tropical dry forest in Panama.

RESEARCH AT THE LEAF LEVEL  Using attached or fresh, detached leaves, measurements of leaf spectral reflectance are made using a spectrometer. The reflectance spectrum of a mature, green leaf exhibits several characteristic features, most notably two broad chlorophyll absorption bands in the visible region (450 and 650 nm), between which lies the ‘green peak’ at 550 nm, and two broad water absorption bands in the near-infrared region (1400 and 1900 nm). High reflectance in the near-infrared is due to light scattering in the leaf mesophyll (Figure 1).

Distinguishing plant species based on leaf spectra requires that they reflect light differently in one or more wavebands. This occurs when traits that control light interaction with a leaf, related to leaf anatomy and biochemistry, differ between species. Smith and Blackshaw (2003) examined weed-crop discrimination at the leaf-level. Using a spectrometer and detached leaves of two crop and five weed species, they determined the species could be correctly identified with 90% overall accuracy.
Studies of plant canopies using hyperspectral technology have been performed at the ground level, in situ, as well as from airborne and satellite-borne remotely sensed imagery.

**Ground level (in situ) research** A spectrometer fibre-optic is placed a few centimetres to a few meters above a plant canopy for measuring spectral reflectance of one to several plants at a time. A major application of ground level remote sensing of weeds is selective herbicide spraying, which can reduce spray volume and herbicide costs and improve weed control. Recent work on ground-level hyperspectral remote sensing includes Vrindts et al. (2002) (sugarbeet, Beta vulgaris L., maize, Zea mays L. and seven weed species), Koger et al. (2004) (pitted morning glory, Ipomoea lacunosa L. in soybean, Glycine max (L.) Merr.), and Peña-Barragán et al. (2006) (Ridolfia segetum Moris in sunflower, Helianthus annuus L.).

![Figure 1. Spectral reflectance of a mature, green leaf of Anacardium excelsum (Bertero & Balb. ex Kunth) Skeels, Parque Natural Metropolitano, Panama.](image)

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Sensor (No. bands)</th>
<th>Spatial resolution</th>
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<tr>
<td>Babysbreath (Gypsophila paniculata L.)</td>
<td>Idaho</td>
<td>CASI (48)</td>
<td>2 m</td>
<td>97% of known infestations identified</td>
<td>Lass et al. (2005)</td>
</tr>
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<td>Brazilian pepper (Schinus terebinthifolius Raddi)</td>
<td>Florida everglades</td>
<td>Probe (128)</td>
<td>5 m</td>
<td>Colonies reliably detected, but not isolated trees</td>
<td>Lass and Prather (2004)</td>
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<td>Giant reed (Arundo donax L.)</td>
<td>South-western California</td>
<td>AVIRIS (224)</td>
<td>4 m</td>
<td>Arundo mapped in 71–95% of image pixels, depending on the method</td>
<td>DiPietro (2002)</td>
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<td>Hoary cress (Cardaria draba (L.) Desv.)</td>
<td>South-western Idaho</td>
<td>HyMap (126)</td>
<td>3 m</td>
<td>86% overall accuracy for infestations with at least 30% cover</td>
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<td>Iceplant (Carpobrotus edulis (L.) N.E.Br.)</td>
<td>Coastal California</td>
<td>AVIRIS (224)</td>
<td>4 m</td>
<td>97% accuracy in mapping presence or absence</td>
<td>Underwood et al. (2003)</td>
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<td>Leafy spurge (Euphorbia esula L.)</td>
<td>South-eastern Idaho</td>
<td>HyMap (126)</td>
<td>3.5 m</td>
<td>Threshold for reliable detection is 40% cover.</td>
<td>Glenn et al. (2005)</td>
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<td>Leafy spurge (Euphorbia esula L.)</td>
<td>South-west Montana rangeland</td>
<td>Probe-1 (128)</td>
<td>3 m</td>
<td>86% overall accuracy</td>
<td>Lawrence et al. (2006)</td>
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<td>Leafy spurge (Euphorbia esula L.)</td>
<td>North-eastern Wyoming</td>
<td>AVIRIS (224)</td>
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<td>Presence or absence detected with 95% overall accuracy</td>
<td>Parker-Williams and Hunt (2004)</td>
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<td>Spotted knapweed (Centaurea maculosa Lam.)</td>
<td>Idaho</td>
<td>CASI (48)</td>
<td>2 m</td>
<td>57% of infestations identified</td>
<td>Lass et al. (2005)</td>
</tr>
<tr>
<td>Spotted knapweed (Centaurea maculosa Lam.)</td>
<td>South-west Montana rangeland</td>
<td>Probe-1 (128)</td>
<td>5 m</td>
<td>84% overall accuracy</td>
<td>Lawrence et al. (2006)</td>
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</table>
Airborne sensors  Airborne hyperspectral sensors offer the greatest opportunities for invasive plant species detection and mapping. Mapping accuracies in excess of 90% have been achieved for several species with distinct spectral characteristics (Table 1). Since they fly at relatively low altitudes (compared to satellites), airborne sensors combine high spectral resolution with high spatial resolution (<5 m). Hyperspectral satellite-borne sensors currently do not offer such high spatial resolution. Airborne imagery provides an important testing ground for future satellite sensors. Drawbacks to airborne hyperspectral data include high costs and lack of repeat visits.

Satellite-borne sensors  EO-1 Hyperion is currently the only satellite-borne hyperspectral sensor. The sensor records 220 wavebands within a spectral range of 400–2500 nm. With a spatial resolution of 30 m, data from this sensor are only suitable for mapping large weed infestations. Improved spatial resolution should soon become a reality. Satellite data are preferable to airborne data due to repeat-visit capability, generally lower costs and greater accessibility (DiPietro 2002). Hyperion data was tested in a recent study by Ramsey et al. (2005), who detected senescing Chinese tallow (Triadica sebifera L.).

REMOTE SENSING OF LIANAS IN PANAMA
Researchers at the Earth Observing Systems Laboratory (EOSL), University of Alberta, are attempting to monitor invasive tropical lianas (woody vines) using hyperspectral remote sensing. Lianas are of concern because they are increasing in dominance in tropical forests (Phillips et al. 2002). Lianas aggressively climb tree trunks to reach the canopy where they form a monolayer of leafy vegetation on top of the host tree. Deleterious effects of liana infestation to the host tree(s) include increased mechanical and wind damage, increased probability of falling, decreased growth rates, and increased mortality rates (Putz 1984). Potential long-term effects include reduced forest regeneration rates and altered tree species composition (Phillips et al. 2002).

Research on the hyperspectral reflectance characteristics of lianas was initiated at the leaf level and continues at the canopy level. Leaf-level studies comparing average spectral reflectance of 12 liana species and five tree species from Parque Natural Metropolitano, Panama, revealed that lianas at this site have higher reflectance in the visible region than trees. The difference in reflectance was related to lower leaf chlorophyll content in lianas compared to trees (Castro-Esau et al. 2004).

In situ spectra of Anacardium excelsum tree crowns with varying levels of liana infestation were measured from a canopy crane and compared. Analysis identified higher visible reflectance on trees with heavy liana infestation compared to those without (Sánchez-Azofeifa and Castro-Esau in press).

Lastly, pixels representing tree crowns of two classes (≥40% liana coverage and <40% liana coverage) were extracted and averaged from a 1 m spatial resolution airborne HYDICE image (210 bands, 400–2500 nm) over Parque Natural Metropolitano. Consistent with previous results at leaf and in situ crown scales, trees with high liana coverage had higher reflectance in the visible region than those without, and could be separated into two groups with 93% overall accuracy (M. Kálacska, S. Bohlman, A. Sánchez-Azofeifa, K.L. Castro-Esau, and T. Caelli unpublished data).

DISCUSSION
Detecting the presence of lianas on tree crowns at Parque Natural Metropolitano appears feasible based on results from these studies at leaf and canopy levels. Distinction between liana and tree spectra may be related to different phenologies or drought coping mechanisms between the two life forms at this park, which is a seasonally dry forest with a prominent dry season from December through April. Differences between the two life forms were not as clear at a tropical wet forest site in Panama.

A significant challenge for detecting lianas is the presence of multiple species and their non-uniform distributions on top of tree crowns. A single tree may be infested with 10 or more liana species while another may be dominated by a single species. The lianas cover varying proportions of the host tree crown. Other tree species are effective at shedding lianas altogether. Specialised processing techniques will be required to deal with the problem of ‘mixed pixels’, for which several scene elements (liana leaves of multiple species, tree leaves, bark, soil) influence the reflectance value of a pixel as measured by a hyperspectral remote sensor.

Monitoring the extent of liana spread in tropical forests is still at an early stage of development. Continued investigation is necessary to determine if operational mapping is feasible in a variety of environmental conditions or ecosystems. Issues of phenology and mixed pixels will be common to invasive plant mapping initiatives in general. In the future, improved opportunities for monitoring invasive plants are anticipated with hyperspectral remote sensing, which is a rapidly-changing technology.
REFERENCES