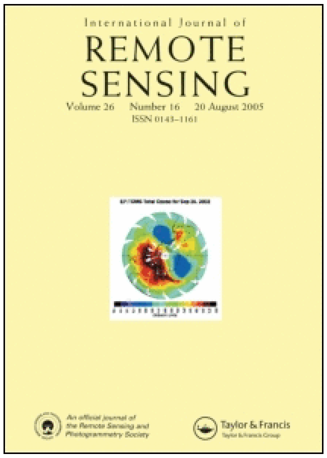

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Letter

Detecting an invasive shrub in a deciduous forest understory using late-fall Landsat sensor imagery

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Landsat TM and ETM+ imagery was used to distinguish areas of high vs. low cover of Amur honeysuckle (*Lonicera maackii*), taking advantage of the late leaf retention of this invasive shrub. *L. maackii* cover was measured in eight stands and compared to 15 Landsat 5 TM and Landsat 7 ETM+ images from spring and autumn dates from 1999 to 2006. Jeffries–Matusita (JM) distance calculations showed potential separability between high vs. low/zero cover classes of *L. maackii* on some late fall images. The Soil Adjusted Atmospheric Resistant Vegetation Index (SARVI2) revealed higher levels of green biomass in high *L. maackii* cover plots than low/zero cover plots for November images only. These findings justify further investigation of the effectiveness of late fall images to map the historical spread of *L. maackii* and other forest understory invasives with similar phenology.

1. Introduction

Invasive species pose significant threats to native species, ecosystem properties and regional economies (Pimentel *et al.* 2000). An important exotic invasive plant in the eastern USA is Amur honeysuckle (*Lonicera maackii*) (Luken and Thieret 1996). Multiple studies have shown that this invasive shrub negatively impacts native understory plants (Gould and Gorchov 2000, Collier *et al.* 2002, Gorchov and Trisel 2003, Hartman and McCarthy 2004, Miller and Gorchov 2004). An understanding of its spatial and temporal invasion dynamics may aid land managers in controlling this threat by highlighting areas that need the most aggressive treatments. Long-term monitoring can determine the relative importance of diffusion versus long distance dispersal, which would enable land managers to prioritize detection and control near advancing fronts or at nascent foci of invasion (Moody and Mack 1988).

In investigating invasion patterns, remote sensing is less time consuming and more informative for larger areas than field-based research alone (Underwood *et al.* 2003). Landsat TM and ETM+ images are particularly useful because they are relatively inexpensive, widely available, and available for dates back to 1984. Peterson (2005) used Landsat ETM+ data to map the invasive grass *Bromus tectorum*. Bradley and Mustard (2006) used similar presence/absence maps

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generated by Landsat MSS, TM, and ETM+ images to examine the invasive spatial patterns of *B. tectorum* from 1973 to 2001.

Remote sensing of invasive plants has only been successful when the invasive is in an aquatic, wetland, riparian, grassland or desert environment, where the absence of tree cover gives the sensors an unobstructed view of the invasive plant (DiPietro 2002, Everitt *et al.* 2002, Goslee et al. 2003, Lass and Prather 2004, Peterson 2005). However, understory plants, including shrubs like *L. maackii*, pose a challenge. Detection of leafy spurge (*Euphorbia esula*) using aerial photography was possible in open areas but not beneath dense woody canopies (Anderson *et al.* 1996), and detection of this perennial herbaceous invader using hyperspectral imaging was highly accurate in prairie and riparian pixels but much less accurate in conifer woodland (Parker Williams and Hunt, 2002, 2004). However, the extended leaf phenology of some forest invaders provides temporal opportunities for satellite detection.

Here, the effectiveness of remote sensing techniques in detecting *L. maackii* from the forest understory was investigated. Because *L. maackii* expands its leaves earlier and retains them later than native trees and shrubs (Trisel 1997), it was predicted that it would be distinguishable in early spring and late autumn images when the tree canopy is bare. Once detected on multiple satellite images, *L. maackii* invasion history could then be reconstructed over time in order to determine the spatial pattern of invasion

2. Methods and materials

2.1 *Study area*

Deciduous forest stands of similar tree composition, flat topography, and contrasting *L. maackii* cover were selected in SW Ohio, USA. The four low/zero cover stands were at Hueston Woods State Park in Preble and Butler counties. The four high cover stands were located in Miami University Natural Areas, Butler County.

2.2 *Vegetation sampling and analysis*

To obtain measurements of forest composition and *L. maackii* density and cover, a 100 m plot was established in each stand. Within each plot, trees (diameter at 1.3 m (dbh)>10 cm), saplings (dbh<1–10 cm, height>2 m), and shrubs (height 1–2 m) were sampled using the point-quarter method along four parallel 100 m transects spaced 25 m apart. Along each transect, four points were chosen at 25 m intervals. In six of the stands the closest tree, sapling, and shrub in each compass quadrant at each point was identified and its distance from the point was measured. The dbh for each tree and sapling was also measured. In the other two stands only the tree nearest each point was identified and measured. In all eight stands the line-intercept method was used to determine the cover of *L. maackii* along each transect.

Standard equations for the point-quarter sampling method (Smith and Smith 2001) were used to calculate stand density and stand basal area (BA) ($m^2 ha^{-1}$) for both trees and saplings, absolute and relative density and BA for each species in the tree and sapling layers, and absolute and relative density of each species in the shrub layer. Percentage cover of *L. maackii* in each stand was calculated as the average of the four transects.

2.3 *Image processing*

In order to determine whether high *L. maackii* cover stands could be distinguished from low/zero *L. maackii* cover stands, spectral separability between plots was evaluated using TM or ETM+ reflectance, Tasseled Cap (Crist and Kauth 1986) brightness (KT-B), greenness (KT-G), wetness (KT-W), and SARVI2 (Huete *et al.* 1997). SARVI2 was selected because it is less sensitive to atmospheric effects and soil background and more sensitive to subtle differences in biomass than the normalized difference vegetation index (NDVI) (Huete *et al.* 1997). A hand-held Global Positioning System (GPS) receiver (Garmin GPSmap 76CSx) was used to obtain UTM coordinates at each corner of the square plots for later use as training sites. Fifteen cloud-free Landsat 5 TM and Landsat 7 ETM+ scenes (WRS-2 Path 20, Row 33) for several dates from spring and fall 1999 to 2006 were obtained from OhioView (http://www.ohioview.org/). No Landsat 7 images acquired after May 2003 (following failure of the scan line corrector) were used. Landsat 5 TM digital numbers (DNs) were converted to Landsat 7 ETM+ equivalents (Vogelmann *et al.* 2001) and all images converted to top-of-the-atmosphere reflectance using the COST model (Chavez 1996) to reduce atmospheric haze. After pre-processing, the two spectral vegetation indices (SVIs) (SARVI2 and KT) were calculated for each date and 10-band images consisting of the original non-thermal TM/ETM+ bands, SARVI2, KT-brightness, KT-greenness, and KT-wetness were created. Jeffries–Matusita (JM) distances were calculated for each date to select the best three-band combination, and determine whether spring or fall imagery was better for distinguishing *L. maackii* presence and absence. To examine phenological differences, mean SARVI2 values (as an indication of green biomass) were also compared from each plot for all dates. Tukey's honestly significant difference (HSD) test was run on mean SARVI2 values for each stand pair and each class (i.e., high vs. low/zero *L. maackii* cover).

3. Results and discussion

All measures of *L. maackii* abundance (percentage cover, absolute and relative density and BA in sapling layer, absolute and relative density in shrub layer) differed greatly between the low/zero and high *L. maackii* cover stands; here only percentage cover is reported (table 1).

Although both spring (March, April, May) and fall (October, November) images displayed JM distances over 1000 (table 2), early spring images (March) indicated no difference in green biomass levels between classes (based on SARVI2 comparisons). Some later spring images (April and May) showed higher SARVI2 values (more green biomass) in low/zero *L. maackii* cover stands. This difference can be attributed to greater cover of spring ephemeral herbs in these stands. Evidence for this greater cover includes the high cover of spring herbs in the Big Woods stand (Carlson and Gorchov 2004) and the higher cover of spring herbs away from v. under *L. maackii* across 10 stands in the SW Ohio area (Collier *et al.* 2002). These patterns in reflectance indicate that spring images are unlikely to be effective for detection of *L. maackii* in forest understory. In order to confidently attribute class separability to the cover of *L. maackii*, high cover sites would have to indicate higher levels of green biomass (*i.e.*, higher SARVI2 values).

Tukey HSD tests (table 2) on November images (04 Nov 1999, 22 Nov 2000, 09 Nov 2001, 12 Nov 2005) showed that all significant differences between high and

Table 1. Forest composition measurements and *L. maackii* density measurements for four low/zero *L. maackii* cover stands and four high *L. maackii* cover stands near Oxford, Ohio.

	Sample site	Canopy dominants	Tree basal area ($m^2 ha^{-1}$)	*L. maackii* percent cover**
Low/zero *L. maackii*	Sugarbush Trail	*Liriodendron tulipifera, Acer saccharum, Fagus grandifolia*	38.9	0
	Horse Trail	*Acer saccharum, Liriodendron tulipifera, Prunus serotina*	38	1.73
	Big Woods Trail	*Acer saccharum, Fagus grandifolia, Liriodendron tulipifera*	34.6	0
	Big Woods Trail 2*	*Acer saccharum, Liriodendron tulipifera, Fraxinus* spp.	NA	0
High *L. maackii* cover	Ecology Research Center (ERC)	*Acer saccharum, Carya tomentosa, Fraxinus* spp.	29.6	57
	Reinhart Reserve	*Acer saccharum, Prunus serotina, Quercus rubra*	24.4	44.9
	Kramer Woods	*Acer saccharum, Liriodendron tulipifera, Fraxinus* spp.	30.1	37.2
	Collin's Run*	*Fraxinus* spp., *Quercus rubra, Acer saccharum*	NA	54

*Field sampling curtailed. Some data not calculated.
**As measured by the line-intercept method.

Table 2. JM distances for the best three-band combination for each image date. The last column shows results of Tukey HSD tests of mean SARVI2. Dates (indicated in month/date/year format) with no significant difference between high *L. maackii* cover and low/zero *L. maackii* cover classes are indicated with "ns", while other dates show which class had significantly higher mean SARVI2 values. The most promising dates indicate higher SARVI2 values for the high *L. maackii* cover class and have higher JM distances when multiple bands are included.

	Date	Best 3-Band Combination			JM distance	higher mean SARVI2
spring	03/01/2002	ETM5	ETM7	KT-W	1211	ns
	03/14/2001	ETM5	SARVI2	KT-B	1012	ns
	03/17/2005	ETM5	SARVI2	KT-B	1102	ns
	03/30/2001	ETM5	SARVI2	KT-B	1057	ns
	04/05/2006	ETM5	ETM7	KT-W	999	low/zero *L. maackii*
	04/15/2004	KT-B	KT-G	KT-W	901	ns
	04/18/2005	ETM4	ETM5	KT-G	910	high *L. maackii*
	05/23/2006	ETM4	SARVI2	KT-G	1194	low/zero *L. maackii*
fall	10/06/2003	ETM2	ETM3	KT-G	715	ns
	10/24/2004	ETM4	SARVI2	KT-W	1010	low/zero *L. maackii*
	11/04/1999	SARVI2	KT-B	KT-W	1230	high *L. maackii*
	11/09/2001	ETM5	SARVI2	KT-B	1056	high *L. maackii*
	11/12/2005	ETM3	ETM5	SARVI2	1177	high *L. maackii*
	11/22/2000	ETM4	ETM5	SARVI2	901	high *L. maackii*
	12/11/2001	ETM4	ETM5	ETM7	828	high *L. maackii*

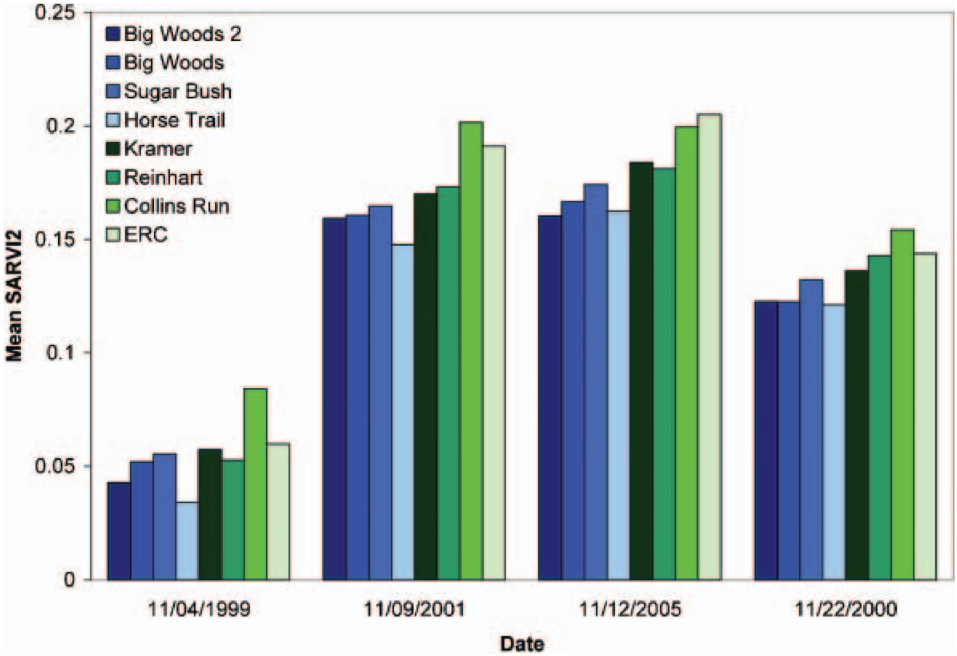

Figure 1. SARVI2 values for November images from 1999 to 2005. *L. maackii* cover ordered from left to right (Big Woods 2=Big Woods=Sugarbush<Horse Trail<Kramer<Reinhart<Collins Run<ERC). Sites in blue are low/zero *L. maackii* cover and sites in green are high *L. maackii* cover. Note that the *x*-axis dates are in month/date/year format and are in 'calendar order' rather than chronological order to illustrate seasonal shifts in green biomass.

low/zero *L. maackii* cover were due to higher mean SARVI2 values (figure 1) in the high cover stands (as would be expected). October images resulted in no significant differences (06 Oct 2003) or differences in the 'wrong direction' (24 Oct 2004). This trend suggests that October images are too early in the leaf-off season to detect *L. maackii*, but that early to mid-November is ideal for this purpose. Many tree leaves have senesced in October, but do not drop for a few weeks, thereby obscuring the satellite's 'view' of the understory. It is important to note that the best date to detect *L. maackii* will also vary each year due to annual differences in temperature and precipitation.

These findings suggest that some factor capable of detection by satellites differed between the two classes. Due to the similar forest composition of the stands (*i.e.*, most were dominated by *Acer saccharum*, total basal areas were similar), it is likely that *L. maackii* density accounted for the differences. This conclusion is supported by the pattern of greater SARVI2 values (*i.e.*, greater green biomass) for high *L. maackii* cover stands in the November images. Furthermore, comparison of early spring images (prior to any leaf expansion) showed low SARVI2 values and no significant differences between classes.

The detection of *L. maackii* with Landsat images in this study is innovative because it is the first to use distinctive leaf phenology to remotely sense an understory species. The results raise the potential for creating historic and current distribution maps of this species and other invasives with extended leaf phenology using late fall Landsat images.

4. Conclusions

Documentation of the historical invasion will facilitate investigation of the processes that shape invasion and modeling invasion and invasion risk

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