RESEARCH ARTICLE

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Assessing an Imperiled Oak Savanna Landscape in Northwestern Ohio using Landsat Data

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ABSTRACT: Land cover change caused by humans represents a major threat to the long term viability of natural areas. It is important to accurately classify and map existing natural areas so that this threat can be fully assessed within a given landscape. Availability of free orthorectified Landsat images through the U.S. Geological Survey provides a potentially valuable tool to evaluate human impacts to natural landscapes. We performed a supervised classification of multi-seasonal Landsat images to test the limits of using these images for mapping mixed landscapes at regional to local scales and to assess land cover changes within the Oak Openings region of Northwestern Ohio. Overall accuracy of our 15-class land cover map was 60% and 69% using traditional and fuzzy set analysis respectively. Overall map accuracy improved to 72% and 79% for traditional and fuzzy set analysis respectively using a more broadly defined 7-class land cover map. Accuracy of individual classes varied considerably, although classes made up of larger patches typically achieved greater accuracy. Human-dominated land cover classes currently occupy 73% of the Oak Openings region while < 3% of the region remains covered by native savannas, prairies, and barrens. Currently 10% of the region is permanently protected, including nearly all remnant savannas and wet prairies > 1 ha. Our findings highlight the utility of using Landsat images to evaluate mixed-use landscapes at regional scales but demonstrate the limitations of using these images at local scales.

Index terms: accuracy assessment, land cover change, Landsat, Midwest oak savanna, vegetation classification

INTRODUCTION

Land cover change caused by human land use increasingly threatens the long-term viability of natural areas across the globe (Foley et al. 2005). By the end of the 21st century, land use change is projected to have a larger global impact on the biodiversity contained within natural areas than any other factor (Chapin et al. 2000). In order to assess the impacts of land use/land cover change on natural systems, it is imperative that natural areas are accurately classified and mapped within the context of other existing land cover types at a scale usable by local land managers and conservation planners.

Satellite-based remotely sensed images are widely used as the basis for developing vegetation-based land cover maps (Fassnacht et al. 2006). Use of remote sensing technology for natural areas mapping offers several advantages over traditional field-based mapping techniques, such as greater efficiency and cost effectiveness per mapping unit, expanded spatial and temporal coverage, and the ability to frequently update existing maps (Xie et al. 2008). Additionally, multispectral sensors which detect electromagnetic radiation beyond visible wavelengths of light provide information on the composition of map features not available using conventional aerial photographs or field-based observations. However, the initial cost of obtaining remotely-sensed images along with the complexity of necessary image processing methods may deter potential end users from otherwise using this technology.

In late 2005, the United States Geological Survey (USGS) helped to address this issue when it began offering geodetically accurate, orthorectified Landsat images over the Internet at no charge (Tucker et al. 2004; NASA 2010). Landsat is the longest running satellite-based imagery program, providing multispectral data for much of the Earth's surface every 16 days with a maximum image resolution of 30 meters. In recent years, Landsat data have been used to effectively assess and map a variety of natural community types at regional scales (Townsend and Walsh 2001; Wang and Moskovits 2001; McCarthy et al. 2005; Domaç and Süzen 2006; Stuart et al. 2006). However, we did not find any peer-reviewed studies evaluating the use of Landsat data at local scales (that could be used, for example, to assess individual management units). The availability of free geodetically accurate Landsat data combined with relatively low-cost image processing software provides land managers and conservation planners with an opportunity to assess the status of many at-risk natural communities, such as Midwest oak savannas.

At the time of European settlement, oak savannas covered large portions of the north central United States (i.e., Midwest oak savannas). These fire-maintained communities persisted within a broad transition zone between the Great Plains and Eastern Deciduous Forest (Nuzzo 1986; Anderson 1998). Following settlement, Midwest oak savannas became heavily fragmented as a result of fire exclusion, agriculture, and urbanization (Nuzzo 1986; Grossmann and Mladenoff 2007). Today, Midwest oak savannas are considered critically endangered in the United States (Noss et al. 1995), as are temperate savannas worldwide (Hoekstra et al. 2005). Although high quality oak savannas currently comprise only ~0.02% of their historic extent throughout the Midwest (Nuzzo 1986), they continue to sustain high levels of biodiversity relative to other upland communities (Leach and Givnish 1999).

We conducted this study to map and assess the current status and distribution of remnant oak savanna communities across a human-dominated landscape in Northwestern Ohio known as the Oak Openings region. Our objectives were: (1) to test the limits of using Landsat images for land cover classification and mapping at regional and local scales; and (2) to identify the current extent, distribution, and protection status of historic Oak Openings plant communities in relation to the surrounding matrix of human-dominated land cover types. It was our intention to use relatively simple classification and mapping protocols that could be easily replicated by other practitioners without the need for detailed vegetation surveys or more advanced image processing/GIS capabilities.

STUDY AREA

The 478-km^2 Oak Openings region of Northwestern Ohio (41º 25’ to 41º 44’ N; 83º 34’ to 84º 2’ W) features one of only a few landscape-scale oak savanna systems remaining in the Midwestern United States (Figure 1). The Oak Openings lies within the Lake Plains physiogeographic region of Ohio’s western Lake Erie basin (Braun 1989). Topography is level to gently rolling, ranging from 180 to 220 meters elevation. Soils are post-glacial beach sand (depth of < 1 m to > 2 m) deposited over clay till; depth to bedrock (limestone and dolomite) is typically > 6 m (Stone et al. 1980). Climate is humid continental; mean monthly temperatures range from -10 ºC to 23 ºC; mean annual precipitation is 81 cm (USDA-

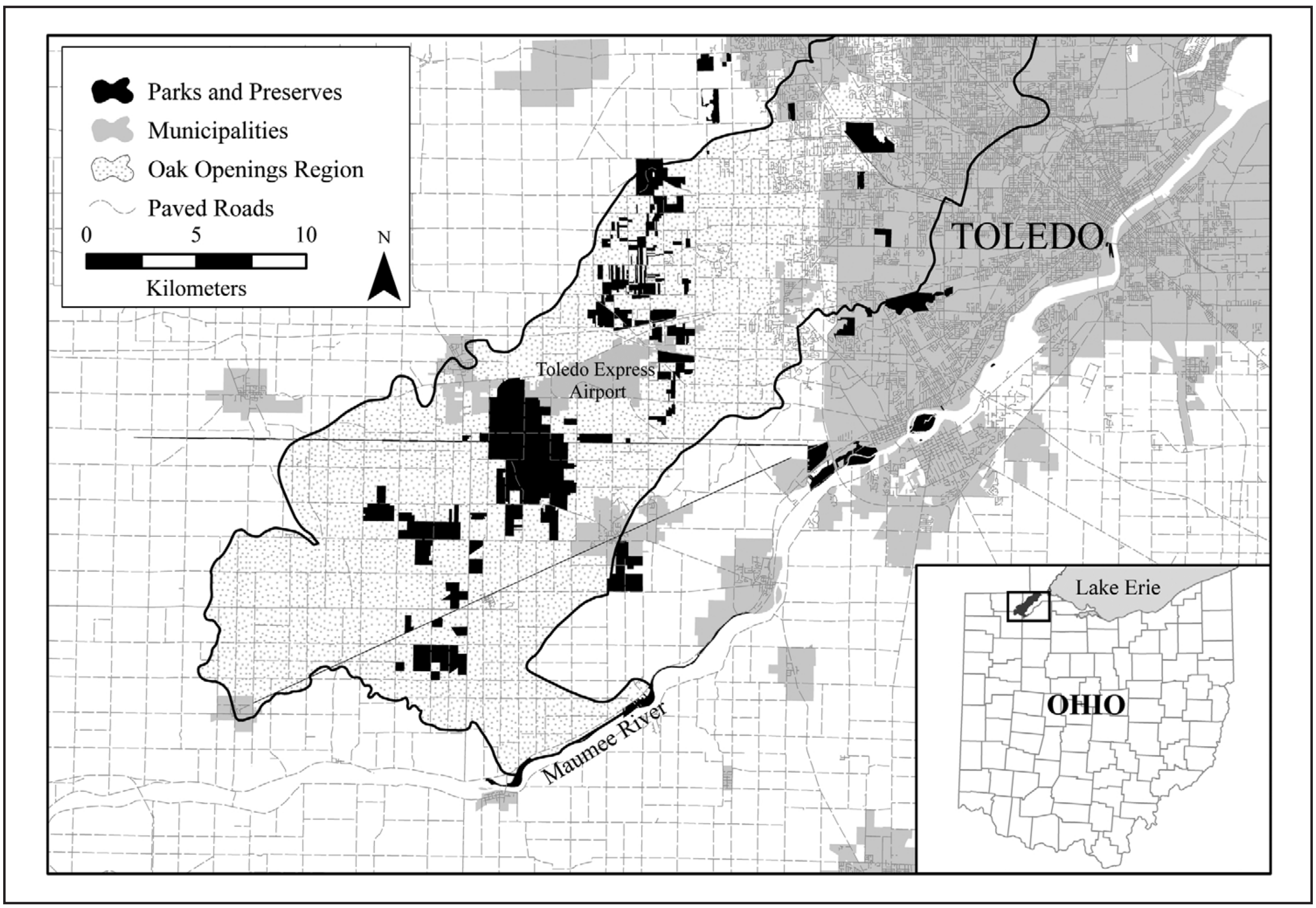

Figure 1. Map of the Oak Openings region of Northwestern Ohio. Parks and Preserves include lands owned and managed by the Metropolitan Park District of the Toledo Area, The Nature Conservancy, Northwestern Ohio Rails-to-Trails Association, Ohio Department of Natural Resources, and The Olander Park System.

NRCS 2010). Historically, the region was characterized by a system of post-glacial beach ridges with oak savannas persisting on the ridge tops and wet prairies persisting within the lowland interdunal areas (Moseley 1928; Brewer and Vankat 2004). Following European settlement, the region's natural communities were systematically altered through drainage, agriculture, fire exclusion, and urban expansion from the Toledo metropolitan area (Mayfield 1976). As with other Midwest oak savanna remnants, the Oak Openings remains a local biodiversity hotspot harboring 143 state endangered, threatened, or potentially threatened plant species (ODNR Division of Natural Areas and Preserves 2008), 24 state endangered, threatened, or 'of concern' animal species (ODNR Division of Wildlife 2008), one federally endangered species (Karner blue butterfly, *Lycaeides melissa samuelis*), and five globally vulnerable or imperiled plant communities (alliances; Faber-Langendoen 2001) within an area that collectively represents < 0.5% of Ohio's total land area.

METHODS

Classification system

We consulted with local plant ecologists and Ohio Natural Heritage Program staff to develop a hierarchical land cover classification system that: (1) was consistent with U.S National Vegetation Classification standards (Comer et al. 2003; Jennings et al. 2009), and (2) could be feasibly mapped under the constraints of a 30-m Landsat image pixel. The resulting classification system shown in Table 1 consisting of 11 natural/seminatural and four cultural classes is based largely on physiognomic characteristics rather than floristic composition, falling roughly within the mid level hierarchy described by Jennings et al. (2009). Based on field observations made during training site selection and map accuracy assessment, we were also able to describe predominant floristic and/or human features associated with each class (Table 1).

Landsat image selection

Using the USGS Global Visualization Viewer (USGS 2009), we selected three Landsat-5 TM scenes acquired on 12 November 2005, 3 March 2006, and 24 June 2006 for Path 20, Row 31 containing our entire study area. We selected Landsat-5 TM images over Landsat-7 ETM+ images to avoid additional image processing required to fully utilize ETM+ images after the loss of the on-board scan line corrector (SLC) in May 2003 (NASA 2010). We chose to evaluate multi-seasonal images (fall, spring, summer) for our map classification because previous research has shown that this improves classification accuracy for mapping both forests (Townsend and Walsh 2001) and grasslands (Peterson et al. 2002). We selected these three images over other available images because they: (1) occurred within a relatively narrow 7-month timeframe, (2) featured 0% cloud cover for the entire study area, and (3) received Level 1 Terrain Corrected (L1T) image processing by USGS. All L1T images include radiometric, geometric, and precision correction (NASA 2010), which allowed us to avoid potentially time-consuming and costly image preprocessing prior to use. According to the Ground Control Points (GCP) Residual Report downloaded with each scene, average Root Mean Square (RMS) error among ground control points for all three scenes was < 4.8m (< 0.16 pixel). All images were downloaded in GeoTif image format projected to Universal Transverse Mercator coordinates (UTM Datum WGS84).

Supervised image classification

We performed a supervised classification of the multi-seasonal images of our study area using ER Mapper 6.4 (Earth Resources Mapping, Inc., San Diego, CA). We selected a maximum likelihood classification model with equal prior probability and general typicality to assign each 30-m image pixel to a single land cover class. Although atmospheric correction was not performed by USGS for the images obtained, we simulated atmospheric correction by applying dark object subtraction (i.e., subtraction of the smallest reflectance value in a given spectral band from all pixels in that band; Chang et al. 2008) to all images prior to classification. We performed the supervised classification using spectral bands 1-5, and 7 from each of the three selected TM scenes so that 18 total spectral bands were used for the classification, each with 30-m pixel resolution. This required a minimum of $n + 1$ (where n = number of spectral bands) or 19 total pixels (1.71 ha) of each training class (ER Mapper 6.4). The thermal infrared band (band 6) from each image was omitted from analysis due to its reduced 60-m pixel resolution. Training sites were delineated using ArcGIS 8.3 (ESRI, Redlands, CA) and imported into ER Mapper 6.4 prior to analysis.

Through preliminary analyses, we found that croplands were especially difficult to classify due to seasonal changes in type and phenology of planted crops. To bypass this problem, we did not use training sites for croplands while performing the supervised classification. Instead, after completing supervised classification of the image data into 14 classes without croplands, we overlaid a cropland "mask" to the 14-class image to produce the final 15-class image. This mask was developed from publicly available croplands data for the study area (USDA 2007), which we visually inspected and corrected using 0.3-m resolution orthophotos acquired in 2006 (OGRIP 2006). After applying the croplands mask, the final 15-class image was clipped to an area representing the historic extent of the Oak Openings region (Brewer and Vankat 2004).

Training site selection

In September 2007, we conducted field surveys throughout the study area to select representative training sites for the various natural/seminatural land cover classes. For each site visited, we took representative site photos, mapped their location using a handheld GPS receiver (Garmin GPS III+), and recorded qualitative site descriptions with information on canopy coverage and characteristic species for each vegetation stratum. We evaluated additional training sites using high-resolution (0.15 to 0.3 m) color orthophotos for classes that could be easily interpreted on the orthophotos such as Upland Coniferous Forests, Perennial

Table 1. Oak Openings region land cover classification. Class descriptions are based on field observations by the authors in September 2007 and September - December 2009.

Class type (7)	Land Cover Class (15)	Class Description
NATURAL /		
Forests / Woodlands	Swamp Forests	Semi-permanent to seasonally-inundated closed canopy deciduous swamps and flatwoods on poorly drained soils; typically dominated by *Quercus palustris* Muench and/or *Quercus bicolor* Willd. *with Acer rubrum* L. common in the subcanopy.
	Floodplain Forests	Closed to open canopy deciduous forests on poorly to moderately well drained soils within floodplains (often broad and poorly defined due to flat topography); near stream channels or ditched waterways, characterized by large *Populus deltoides* Marsh., *Platanus occidentalis* L., and dead / dying *Fraxinus* sp. Broader floodplains often characterized by young even-aged stands of *Acer saccharinum* L., *Populus* sp., *Fraxinus* sp., and *Quercus* sp.
	Upland Deciduous Forests	Closed canopy mesic to dry forests (also a few open canopy woodlands) on moderately to well drained soils on slopes and ridges; typically dominated by *Quercus velutina* Lam., *Quercus alba* L. and/or *Quercus rubra* L.; understory characterized by *Sassafras albidum* (Nutt.) Nees, *Prunus serotina* Ehrh., *Acer rubrum* and low growing *Vaccinium* sp.; herbaceous layer often characterized by continuous cover of *Carex pensylvanica* Lam.
	Upland Coniferous Forests	Mostly monospecific plantations of *Pinus* sp. with few adventive examples. Did not occur in the Oak Openings prior to European settlement (Moseley 1928).
Savannas	Upland Savannas	Open canopy stands of *Quercus velutina* and/or *Quercus alba* (with some *Quercus palustris* Muenchh. and *Quercus coccinea* Muenchh.) on well drained soils with a well developed shrub and/or herbaceous layer typically dominated by warm-season grasses (primarily *Andropogon gerardii* Vitm. and *Sorghastrum nutans* (L.)Nash.) and forbs.
Shrublands	Wet Shrublands	Semi-permanent to seasonally-inundated shrublands on poorly drained soils. Most observed sites were dominated by dense monospecific stands of *Rhamnus frangula* L. A few sites featured a more open shrub layer characterized by *Salix* sp., *Cornus* sp., *Cephalanthus occidentalis* L., and *Physocarpus opulifolius* (L.) Maxim. and a well developed herbaceous layer characterized by *Carex* sp.

Continued

Table 1. Continued

Prairies & Meadows	Wet Prairies	Semi-permanent to seasonally-inundated prairies on poorly drained soils. Trees nearly to entirely absent, shrubs typically sparse or absent, herbaceous layer dominated by *Carex* sp., and/or *Calamagrostis* sp.
	Upland Prairies	Mesic to dry sand prairies characterized by warm-season grasses (typically *Andropogon gerardii, Sorghastrum nutans*, and *Schizachyrium scoparium* (Michx.) Nash) and forbs. Trees nearly or entirely absent, shrub layer typically sparse or absent.
	Sand Barrens	Early successional herbaceous communities on sand blowouts and recently-disturbed well drained soils; bare sand typically exceeds 50% of total ground cover. Characterized by *Schizachrium scoparium, Andropogon virginicus* L., *Aristida* sp., annual forbs and drought tolerant species. Trees nearly or entirely absent. Shrub layer (characterized by *Rubus* sp. when present) typically sparse or absent. Many sites are also heavily influenced by Eurasian species.
	Eurasian Meadows	Mesic to dry cool-season grasslands and oldfields dominated by Eurasian species such as *Festuca* sp., *Poa* sp., and *Bromus* sp. Unmanaged sites often characterized by invasive shrubs such as *Rosa multiflora* Thunb. and *Eleaegnus umbellata* Thunb.
Water	Perennial Ponds	Permanent excavated ponds, impoundments, and former sand mines; not associated with natural surface water drainage; did not occur prior to European settlement.
CULTURAL		
Built-Up	Dense Urban	Areas dominated by large tracts of asphalt, parking lots, flat rooftops and other impermeable surfaces.
	Residential / Mixed	Areas of closely associated residential structures, mowed lawns and shade trees (typically all found within a 30-m map pixel); also includes roadways and maintained ditches where trees are absent.
Vacant	Turf / Pasture	Large areas of frequently mowed turf grasses such as cemeteries, athletic fields and golf courses; livestock pastures.
	Croplands	Characterized by large fields of row crops, primarily corn and soybeans.

Ponds, and the various cultural classes. For the final classification, we used 106 training sites for 14 classes totaling 356 ha (average of 8 training sites and 25 ha per class).

Accuracy assessment

We assessed the accuracy of the final land cover map by comparing a sample of individual map pixels of each land cover class to specific points on the ground to produce a traditional "crisp" classification where each point on the ground represents only a single land cover class (Foody 2002). We compiled the results into a standard confusion or error matrix to evaluate "producer's accuracy" (corresponding to errors of omission) and "user's accuracy" (corresponding to errors of commission) for the final map. Because traditional "crisp" accuracy assessment requires that each sample location is assigned to only a single class, areas of ambiguity, such as ecotones between plant communities, are not represented. Additionally, the magnitude of misclassification errors cannot be judged from the final confusion matrix (Gopal and Woodcock 1994). Therefore, we also evaluated map accuracy using fuzzy set theory by applying the 'linguistic scale' of Gopal and Woodcock (1994) to each sample pixel on the ground for its agreement with each land cover class as follows:

1. *Absolutely Wrong*: The answer is unacceptable.
2. *Understandable but Wrong (Not Right)*: Not a good answer. There is something about the site that makes the answer understandable, but there is clearly a better answer. This answer would pose a problem for a user of the map.
3. *Reasonable or Acceptable Answer*: Maybe not the best possible answer but it is acceptable; this answer does not pose a problem to the user if it is seen on the map.
4. *Good Answer*: Would be satisfied to find this answer given on the map.
5. *Absolutely Right*: No doubt about the match.

Townsend and Walsh (2001) provide a more detailed description of this approach for classifying vegetation-based land cover maps.

We conducted a stratified random sampling of 25 map pixels for each land cover class (375 total pixels) using the individual 30-m pixel as the sampling unit. To ensure a reasonable distribution of samples across the entire study area, we set the minimum distance between sample points to 150 meters (5 pixels). In order to boost sample size without increasing substantially the amount of work required for field validation, we chose to also evaluate the four neighboring pixels adjacent to each accessible sample pixel following Nusser and Klaas (2003). Pixels located within the training sites used for the supervised classification were excluded from selection. Prior to pixel validation, we assigned random identification numbers to each sample location to prevent prior knowledge from biasing the results.

We initially evaluated sample pixels using high resolution (0.3 m) color orthophotos acquired in 2006 (OGRIP 2006). For samples that we could confidently identify using orthophotos (e.g., Croplands, Dense Urban, Residential/Mixed, Perennial Ponds, Upland Coniferous Forests), we conducted no ground validation. For all other samples, we visited each pixel cluster (i.e., the central pixel and its four neighbors) on the ground using a handheld GPS receiver and high resolution orthophoto maps. We conducted ground visits from September through December 2009 to evaluate structural vegetative characteristics. For each pixel cluster, we took representative site photos, recorded qualitative site descriptions with information on canopy coverage and characteristic species for each vegetation stratum, and assigned class membership using both "crisp" and "fuzzy" classes for each of the five pixels within the pixel cluster. We also noted any obvious changes on the ground compared to the 2006 orthophotos.

Regional assessment

To assess land cover changes in the Oak Openings region since European settlement, we compared the final land cover map with GIS data obtained from historic vegetation maps of the study area (Brewer and Vankat 2004). We evaluated the current protection status for each natural/seminatural land cover class using GIS shape files compiled for all permanently protected parks and preserves within the study area (Figure 1). We used ArcGIS 8.3 to compile per-class data on total area, number of discrete landscape patches, mean patch area, and related landscape characteristics.

RESULTS

Map accuracy assessment

The completed land cover map of the Oak Openings region is shown in Figure 2. Of the 1875 pixels selected to assess the map's accuracy, 1392 pixels (74%) were evaluated. A total of 710 pixels (38%) were evaluated on the ground, 682 pixels (36%) were evaluated from orthophotos, while 483 pixels (26%) were not evaluated because they could not be reliably classified from orthophotos and occurred on private properties where permission was not secured to inspect them on the ground.

Overall accuracy of the final 15-class map using a traditional "crisp" classification was 60% (Table 2). Kappa (a measure of agreement due to chance, from 0 – 1, where 0 indicates agreement entirely due to chance, while 1 indicates true agreement between mapped classes and reference points) was 0.56. Producer's accuracy ranged from 21% for sand barrens to 90% for upland savannas. User's accuracy ranged from 11% for sand barrens to 96% for perennial ponds. Overall map accuracy improved to 69% using the 'RIGHT' function of Gopal and Woodcock (1994), where fuzzy membership is based on the frequency that each mapped class is assigned a score of 3, 4, or 5 on the linguistic scale for a given field validation site. Accuracy of individual classes using the 'RIGHT' function ranged from 16% for sand barrens to 99% for perennial ponds.

By moving up one level in the land cover classification hierarchy (seven total classes), overall map accuracy improved to 72% with a kappa of 0.65 (Table 3). Producer's accuracy ranged from 56% for shrublands to 90% for savannas while user's accuracy ranged from 45% for savannas to 96% for water. Overall map accuracy using the

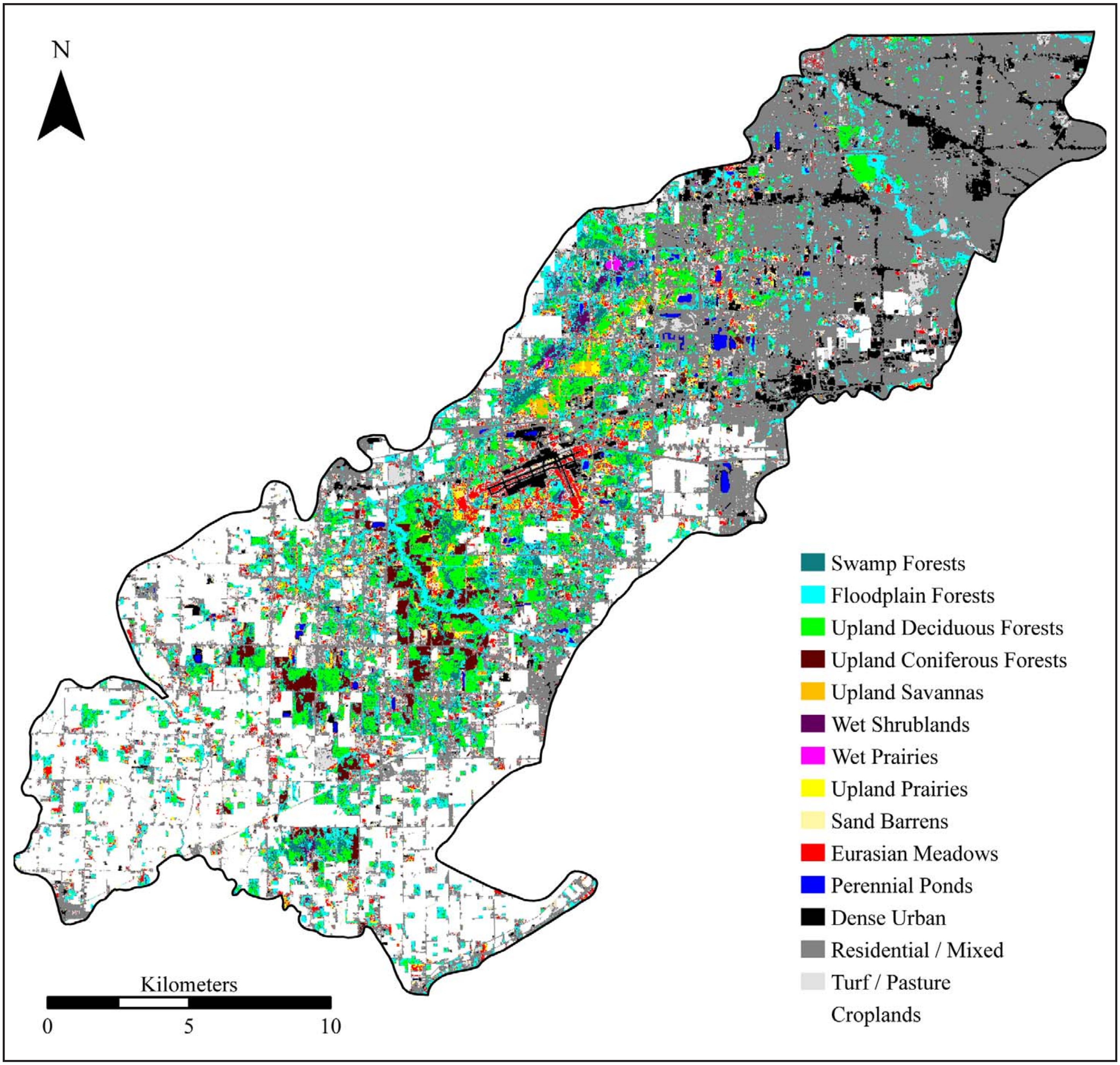

Figure 2. Land cover map of the Oak Openings Region of northwestern Ohio.

'RIGHT' function increased to 79% with individual class accuracy ranging from 47% for savannas to 99% for water.

Status of Oak Openings region

According to the final land cover map, since European settlement, 73% of the Oak Openings region has been converted to human-dominated land uses while only 27% of the region remains classified as natural or seminatural (Figure 2; Table 4). Nearly 40% of the region has become built-up for urban/residential uses concentrated in the northeastern portion of the region (closest to the city of Toledo's urban core). Cultivated croplands (primarily row-crops of corn and soybeans) make up 27% of the region, concentrated in the southwestern portion of the region. Three-fourths of the Oak Openings' 13,000 ha of remaining natural/seminatural lands, concentrated in the central portion of the region, were classified as forests and woodlands.

Savannas, wet prairies, upland prairies, and sand barrens, which are of greatest interest to local conservation organizations, have faced severe declines since European settlement (Table 4). According

Table 2. Error matrix and accuracy for the 15-class Oak Openings region land cover map. The RIGHT function evaluates whether the mapped class is acceptable for a given reference site using the linguistic scale of Gopal and Woodcock (1994).

		Actual Land Cover (from reference sites)																User's	
	Class	SF	FF	UD	UC	US	WS	WP	UP	SB	EM	PP	DU	RM	TP	CR	Row Total	Accuracy (%)	RIGHT (%)
	SF	**28**	10	16		1	6	1						1			63	44	59
	FF	4	**38**	28	1		14	5		1	9	4		9	1		114	33	40
	UD	7	4	**66**		1		3			1			5			87	76	83
	UC	5	7	5	**56**						1			3			77	73	78
	US		2	8		**27**	1		6	3	11				2		60	45	47
	WS	2	2			1	**43**	4						6			58	74	83
Classified	WP						5	**36**			8	2		3			54	67	72
Land Cover	UP		3	3			1		**7**	7	13			4	4	1	43	16	23
(from map)	SB								1	**6**	4		3	16	11	16	57	11	16
	EM			1	1		2	1	5	1	**39**			10	13	1	74	53	59
	PP		1									**79**		2			82	96	99
	DU									7		17	**61**	19	1	6	111	55	68
	RM	1	3	7	9		5			2	6	4	17	**175**	26	12	267	66	79
	TP			1				6	4	1	3			32	**41**	10	98	42	64
	CR							1			9			5	3	**129**	147	88	91
Column Total		47	70	135	67	30	77	57	23	28	104	106	81	290	102	175	**1392**	**Overall**	
Producer's Accuracy (%)		60	54	49	84	90	56	63	30	21	38	75	75	60	40	74		**60%**	**69%**

Kappa = 0.56

SF=Swamp Forests
FF=Floodplain Forsts
UD=Upland Deciduous Forests
UC=Upland Coniferous Forests
US = Upland Savannas
WS=Wet Shrublands
WP=Wet Prairies
UP=Upland Prairies
SB=Sand Barrens
EM=Eurasian Meadows
PP=Perennial Ponds
DU=Dense Urban
RM=Residential/Mixed
TP=Turf/Pasture
CR=Croplands

Table 3. Error matrix and accuracy for the Oak Openings region land cover map using seven classes. The RIGHT function evaluates whether the mapped class is acceptable for a given reference site using the linguistic scale of Gopal and Woodcock (1994).

		Actual Land Cover (from reference sites)								User's	
	Class	For	Sav	Shr	Pra	Wat	Bui	Vac	Row Total	Accuracy (%)	RIGHT (%)
	For	**275**	2	20	21	4	18	1	341	81	87
	Sav	10	**27**	1	20			2	60	45	47
Classified	Shr	4	1	**43**	4		6		58	74	83
Land Cover	Pra	8		8	**128**	2	36	46	228	56	58
(from map)	Wat	1				**79**	2		82	96	99
	Bui	20		5	15	21	**272**	45	378	72	80
	Vac	1			24		37	**183**	245	75	87
Column Total		319	30	77	212	106	371	277	**1392**	**Overall**	
Producer's Accuracy (%)		86	90	56	60	75	73	66		**72%**	**79%**

Kappa = 0.65

For=Forests & Woodlands Pra=Prairies & Meadows Vac=Vacant
Sav=Savannas Wat=Water
Shr=Shrublands Bui=Built-up

to the final land cover map, these areas collectively represent < 3% (1400 ha) of the region's land area. Wet prairies appear to have faced the sharpest declines. Once occupying over one-quarter of the region (Brewer and Vankat 2004), wet prairies now represent < 0.1% (40 ha) of the Oak Openings' land area. Based on our field observations, many of the nearly 200 ha of wet shrublands identified on the land cover map are likely former wet prairies now dominated by dense stands of the invasive shrub glossy buckthorn (*Rhamnus frangula* L.).

Currently 10% (4608 ha) of the Oak Openings region's land area has been permanently protected as parks and preserves (Figure 1; Table 4). Seventy-one percent (3283 ha) of all parks and preserves were classified as forests/woodlands, including 627 ha of non-native coniferous forests planted on public lands in the mid twentieth century for soil stabilization. An additional 16% (725 ha) of all parks and preserves were classified as cultural land cover types of little or no conservation interest. Although parks and preserves currently contain 39% of all areas classified as savannas, two-thirds of all wet prairies, and 17% of all upland prairies and barrens, these classes collectively represent just 7% of all conservation lands in the region. When evaluating the status of larger patches on the landscape (≥ 1 ha), nearly all areas classified as oak savannas or wet prairies are contained in parks and preserves, while the majority of areas classified as upland prairies or sand barrens remain unprotected (Table 4).

DISCUSSION

Map Evaluation

We developed a working land cover map of the Oak Openings region with two primary objectives in mind. First, we wanted to test the limitations of our relatively simple classification and mapping procedure to evaluate regional- to local-scale mixed-use landscapes using widely available Landsat data. The Oak Openings provided an ideal test case to assess mapping accuracy at both regional and local scales because it consists of a heterogeneous mix of human dominated, forested, and grassland communities. Our detailed 15-class map of the Oak Openings achieved an overall map accuracy of 60% using traditional "crisp" classification and 69% using fuzzy classification. Overall accuracy of the map improved to 72% (crisp) and 79% (fuzzy) when we considered the next higher level in the classification hierarchy. Although overall classification accuracy would likely have improved by including ancillary data (e.g. soils, topography, geology) into our model (Domaç and Süzen 2006), we wanted to keep our methods as simple as possible so that they could be applied by other practitioners with limited remote sensing or modeling capabilities.

There are currently no universally accepted standards for evaluating map accuracy (Xie et al. 2008). A target of 80% overall map accuracy is often used as an acceptable standard for vegetation-based land cover maps (Smith et al. 1999). However, evaluating a map's accuracy is not a clear-cut process because it depends largely on the intended use of the map (Crist and Deitner 2007). The error matrix provides important information for end users to assess whether the map meets their intended purpose. In the case of the Oak Openings land cover map, higher levels of accuracy were achieved when evaluating forests and woodlands (86% producer's accuracy and 81% user's accuracy; Table 3) compared to prairies and meadows (60% producer's

Table 4. Summary of land cover map results for the entire Oak Openings region and lands permanently protected as parks and preserves.

	Entire Region						
		Total		Patches >1 ha		Patches >5 ha	
Class	% area	# patches	Area (ha)	#	Area (ha)	#	Area (ha)
Natural / Seminatural	27.2	5219	12989	683	12107	252	11107
Forests and Woodlands	20.4	3488	9735	662	9122	256	8184
Swamp Forests	3.1	5100	1496	206	656	29	297
Floodplain Forests	8.9	9406	4259	804	2457	90	991
Upland Deciduous Forests	6.4	4336	3073	450	2303	111	1559
Upland Coniferous Forests	1.9	1289	907	116	709	41	544
Savannas (Upland Savannas)	0.8	1956	370	22	80	4	49
Shrublands (Wet Shrublands)	0.4	846	193	17	78	4	46
Prairies & Meadows	5.1	6242	2438	432	1340	53	559
Wet Prairies	0.1	116	40	4	22	2	15
Upland Prairies	1.3	3327	610	57	122	3	32
Sand Barrens	0.8	2152	359	27	48	-	-
Eurasian Meadows	3	4798	1429	220	589	16	184
Water (Perennial Ponds)	0.5	309	253	48	201	12	109
Cultural							
Built-up	39.2	6617	18749	642	17488	153	16414
Dense Urban	3.8	1957	1833	240	1434	60	1043
Residential / Mixed	35.4	7573	16915	679	15469	155	14331
Vacant	33.6	7236	16042	582	14252	157	13380
Turf / Pasture	6.6	9278	3141	545	1397	38	415
Croplands	27	305	12901	245	12863	134	12560
Total mapped	100		47779				
	Parks and Preserves						
	Total under protection			Patches >1 ha		Patches >5 ha	
Class	% area	# patches	Area (ha)	#	Area (ha)	#	Area (ha)
Natural / Seminatural	30	219	3883	83	3842	52	3773
Forests and Woodlands	34	370	3283	113	3214	49	3072
Swamp Forests	42	1619	631	93	336	18	195
Floodplain Forests	22	1984	931	141	549	16	313
Upland Deciduous Forests	36	1015	1094	134	904	44	716
Upland Coniferous Forests	69	279	627	78	579	33	472
Savannas (Upland Savannas)	39	409	142	13	61	4	48
Shrublands (Wet Shrublands)	47	293	90	14	46	3	20
Prairies & Meadows	14	532	353	66	244	18	149
Wet Prairies	66	33	26	4	21	2	15
Upland Prairies	22	422	135	24	59	1	13
Sand Barrens	7	113	26	2	5	-	-
Eurasian Meadows	12	543	166	24	59	2	11
Water (Perennial Ponds)	6	11	15	3	13	1	8

Continued

Table 4. Continued

Class			Parks and Preserves: Total under protection % area	# patches	Area (ha)	Patches >1 ha #	Area (ha)	Patches >5 ha #	Area (ha)
Cultural									
	Built-up		3	1284	498	81	219	6	76
		Dense Urban	<1	32	8	2	3	-	-
		Residential / Mixed	3	1289	490	78	210	6	72
	Vacant		1	426	227	26	133	9	99
		Turf / Pasture	3	382	103	9	21	-	-
		Croplands	1	58	124	17	107	7	83
Total mapped					4608				

accuracy and 56% user's accuracy; Table 3). This disparity in map accuracy may be attributed at least in part to patch size. Mean patch size of forests and woodlands was 3.7 ha compared to a mean patch size of 0.5 ha for grasslands and meadows (derived from Table 4). Smaller patches are especially susceptible to map pixel misregistration and field validation/GPS errors.

We were particularly interested in evaluating the accuracy of the final Oak Openings land cover map in relation to classes of specific conservation interest to likely map users. For savannas, 27 out of 30 field validation sites were correctly classified (90% producer's accuracy; Table 2). However, 33 field validation sites that were not savannas were incorrectly classified as savannas resulting in a user's accuracy of 45% (Table 2). This suggests that map users will likely find most existing savannas within areas shown as savannas on the map but that many areas shown as savannas on the map are also likely to include other unrelated classes. An appropriate use of the map in this case would be to select areas for more targeted ground surveys to find potential restoration sites or previously unidentified savanna remnants.

The map generally performed poorly for discriminating among upland prairies and sand barrens (Table 2). Again, patch size relative to the minimum mapping unit (i.e., a 30-m Landsat pixel) was a major contributing factor. Mean patch size of upland prairies and sand barrens was roughly the area of two map pixels (0.18 ha). The map was much better at classifying wet prairies where the mean patch area was equivalent to roughly 4 map pixels (0.36 ha). Perhaps another explanation for the map's inability to accurately classify native prairie types is that many native prairies may be too degraded from invasion of exotic cool-season species and are, therefore, spectrally too similar to other human-influenced cover types. For example, only one out of 23 upland prairie field validation sites and none of the 28 sand barren sites were assigned a fuzzy class membership score of 5 (absolutely right) compared to 18 out of 57 (31%) of wet prairies. The appearance of large clusters of Eurasian meadow pixels located in close proximity to upland prairie and sand barren classes, especially in the central portion of the region, lends some support to this hypothesis.

Our findings generally suggest that classification of multi-seasonal Landsat images provides a useful assessment tool for evaluating mixed-use landscapes at regional scales, especially those characterized by medium to large patches. However, Landsat data is probably unsuitable for evaluating local scale areas such as individual management units, especially when these areas are dominated by small patches (< 0.2 ha). Although use of fuzzy classification techniques improved overall map accuracy, our results highlight the challenge of using discrete classes for mapping vegetation occurring along a continuum of community types. It is worth noting that high-resolution (< 4 meter) satellite imagery (e.g., QuickBird, IKONOS) is commercially available which could improve map accuracy, especially for troublesome vegetation types and small patches on the landscape (*refer to* Xie et al. 2008). However, these images are likely cost prohibitive to many practitioners, especially for use at regional scales. We believe that our simple approach to evaluating Landsat data offers an inexpensive option for assessing areas where detailed land cover maps are lacking provided that the limitations of the 30-m Landsat pixel are considered.

Implications for Midwest Oak Savannas

Our second major objective in completing this study was to assess the current status and distribution of historic plant communities in the Oak Openings region. Even taking into account various sources of map error, our results clearly demonstrate the large magnitude and extent of loss faced by native savannas, prairies, and barrens. Using a pre-settlement map of the region (Brewer and Vankat 2004), we estimate that collectively these communities have declined 96% since European settlement of the region. In contrast, the extent of native forest communities (i.e., swamp forests, floodplain forests, and upland deciduous forests) across the region has declined by only an estimated 20% when compared to the historic extent of oak woodlands and floodplain forests at the time of European settlement (Brewer and Vankat 2004). This phenomenon is almost certainly due to the loss of natural fire regimes since European settlement, allowing historic savanna and prairie communities to revert to woodlands and forests through natural succession.

In recent years, local conservation organizations have focused much of their funding on acquisition of unprotected natural areas (Abella et al. 2007). Currently, 10% of the region's land area has been secured as parks and preserves. While additional protection of natural areas within the region is certainly encouraged, the final land cover map shows that there are essentially no large remnant savannas, sand barrens, or wet prairies remaining on unprotected lands. Although the majority of existing upland prairies remain unprotected in the region, further examination shows that the only large patches of unprotected upland prairie occur within the bounds of Toledo Express Airport. Based on the known extent of pre-settlement Oak Openings communities (Brewer and Vankat 2004), there likely remain numerous opportunities to restore prairies and savannas within areas now classified as forests. Our findings clearly reinforce the need for continued ecological restoration and management throughout the Oak Openings, especially within existing parks and preserves. It is our intent that the final land cover map is used by local land managers and conservation planners as a decision-making tool to assist with development of a collaborative conservation and restoration plan for the Oak Openings region.

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