Documenting Changes in the Natural Environment of Indianapolis-Marion County from European Settlement to the Present

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TECHNICAL REPORT

Documenting Changes in the Natural Environment of Indianapolis-Marion County from European Settlement to the Present

by Robert C. Barr, Bob E. Hall, Jeffrey S. Wilson, Catherine Souch, Greg Lindsey, John A. Bacone, Ronald K. Campbell and Lenore P. Tedesco

Geographic Information Systems integrate historic and contemporary records and provide locations of potential restoration sites.

With the increased concern about the sustainability of urban areas, managers of urban environments are placing new emphasis on urban ecology and management of forests and other natural areas. Citing aesthetic, ecological, and energy-related benefits, some cities and organizations have established ambitious goals for restoration of tree cover. When programs to achieve tree-cover goals are cast in terms of restoration, an implicit assumption is that managers know the types of ecosystems that should be recreated. In reality, our understanding of historical ecological structure and function is still evolving.

In this paper we report on the use of Geographic Information Systems (GIS) to integrate historic maps of vegetation (ca. 1820) and soils (1911) with more recent (1997) digital soils and wetland maps and multi-spectral satellite imagery to estimate changes in the area and distribution of natural areas in Indianapolis-Marion County over time. The work was initiated by land managers and restoration specialists at the Indianapolis Department of Parks and Recreation who are responsible for development and management of a system of natural areas in the city, and frequently are asked to supply areas for mitigation projects. If these projects can be sited on areas that originally were occupied by the desired plant community, the projects may have a better chance of success (Mitsch and Gosselink 2000). Unfortunately, in Marion County, and many other urban areas, little is known about the original distribution of natural areas, and what is known generally has been difficult for land managers to access. The approach presented here provides a first approximation of the distribution of areas of medium/dense tree cover and change through time, which we believe is of general value to urban land managers.

Mapping Tree Cover in Urban Environments

Tree cover in urban areas can be mapped using visual interpretation or digital image processing of remotely sensed data such as aerial photography and satellite imagery. Digital image processing techniques are often cited as a more objective approach and provide the additional ability to integrate data from multiple regions of the electromagnetic spectrum (Tin-Seong 1995, Barnsley and Barr 1996, Moller-Jensen 1997, Jensen and Cowen 1999). Digital processing techniques can also be significantly more cost effective for

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analyzing large areas. Ventura and Harris (1994), for example, compared a number of different image interpretation methodologies and remotely sensed data sources for urban land cover mapping in the city of Beaver Dam, Wisconsin. They concluded that digital image processing of satellite imagery was the most cost-effective approach for areas larger than 51 square miles (130 km²), but that a larger number of land-cover classes were defined with greater accuracy using visual interpretation of higher resolution aerial photography. Regardless of the approach used to map urban land-cover characteristics, GIS are essential for integrating and interpreting these and related spatial data sources. GIS are particularly useful for linking and interpreting sets of spatial data that were produced at different points in time using different techniques. Modern analyses of tree cover routinely integrate, for example, hard copy maps, digital maps and databases, and data derived from multi-spectral remotely sensed imagery. In this paper we demonstrate how we apply this approach to historic data as well.

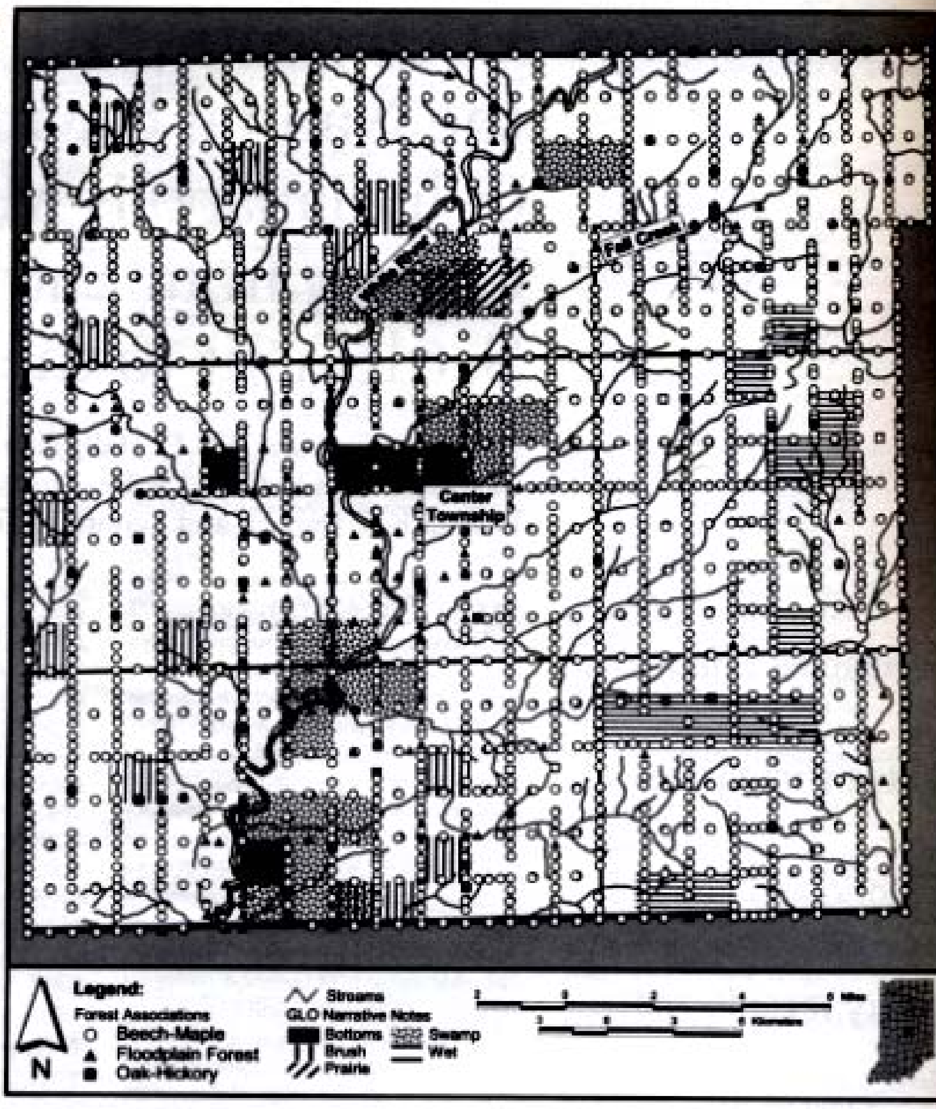

Figure 1. General forest associations based on General Land Office witness tree locations supplemented with area descriptions from the surveyor's narrative notes.

Data Sources and Methods

Pre-European Settlement Vegetation Communities

For our study we used information on pre-European settlement vegetation, both aerial cover and composition from three primary sources: 1) General Land Office Surveys (1820-1822), 2) 1911 soil survey of Marion County, and 3) early settlers accounts of Marion County, dating from approximately 1820 to 1882, and their interpretations.

The General Land Office Surveys (1820-1822)

The U.S. General Land Office (GLO) survey notebooks for Indiana (GLO 1799-1834) provide the single best record of pre-European settlement vegetation (Bourdo 1956, Lindsey 1966, Delcourt and Delcourt 1996, Batek and others 1999). General Land Office records have been used to create pre-settlement vegetation maps for many states (Marshner 1930, Lindsey and others 1965, Gordon 1969, Curtis 1959, Schaetzl and Brown 1996). The GLO survey of Marion County was conducted from 1820-1822 and has been used by several researchers to describe the pre-settlement vegetation (Blewett and Potzger 1951, Potzger and others 1956, Brothers 1994). We expand on this earlier work by using GIS to compare these data with additional data sources, such as soil associations and topography. We believe this method allows resource managers and restorationists to better utilize these invaluable early records (Radeloff and others 1999).

The procedures for a GLO survey vary with the date the survey was done and the special instructions that were given to the contract surveyors. In general the surveyors walked the perimeter of each square-mile section (Bourdo 1956), and as they walked they filled in two prepared forms. One form was a running narrative intended to describe the general quality of the land. Terms such as "Bottoms," "Swampy," and "Grass Land" commonly were used. The second form described the vegetation found at the intersection of section and quarter-section lines. The common name of the tree found at or near the intersection was recorded, along with the diameter of the tree and its distance and compass bearing from the actual surveyed intersection point. A list of the tree species recorded in the Marion County GLO survey, the number of each species recorded, and the inferred forest association (Deam 1932, Lindsey and others 1965, IDNR Division of Nature Preserves 1980, Brothers 1994, Swink and Wilhelm 1994) is presented in Table 1. While the GLO records certainly provide the best primary account of pre-European settlement vegetation (Figure 1), questions have been raised about whether the data can reflect a surveyor's bias toward large trees, trees of economic value, and trees whose bark is easy to mark, such as American beech (Buordo 1956, Manies and Mladenoff 2000). Studies by Delcourt and Delcourt (1974, 1977) suggest, however, that in their study areas, surveyor bias in selecting tree species was not important except for one tree species in one habitat.

In order to integrate the witness tree information with other sources of data, we digitized the GLO survey data onto Township and Range boundaries using a grid constructed in AutoCAD™ v. 13. At each intersection of the section lines, a point was added to represent a tree occurrence. Additional trees were recorded along the section lines at each half section or each quarter section. The most common number of surveyed locations between intersections was three. Approximately one-third of the county was surveyed at a higher resolution of five surveyed points between quadrant vertices of one mile. The area with higher resolution is located in the center of the county near the confluence of the White River and Fall Creek, the two largest drainages in the county. This area includes most of what is now known as Center Township as well as some areas in the surrounding townships (Figure 1). For each point in the database, fields were added listing the symbol, common name, scientific name, and diameter at breast height (DBH) for each tree as recorded in the GLO records, as well as the inferred association: beech-maple, oak-hickory, or floodplain.

One criticism of maps produced from GLO survey data is that no boundaries between vegetation associations are shown. In addition, important features may be

Table 1: Tree species data from the records of the General Land Office Survey of Marion County (1820-1822) and their status as indicator species (based on Kricher 1988) for forest community type (associations). All indicator species listed as present in Marion County by Deam (1932).

Recorded Name of Witness Tree	Inferred Scientific Name	Percent of total	Number Surveyed	Average DBH (in)	Assumed Forest Association
Basswood	*Tilia americana*		22	13	Floodplain forest and Uplands
American beech	*Fagus grandifolia*	40	1455	15	Beech-Maple
Bigtooth aspen	*Populus grandidentata*		3	14	
Black maple	*Acer nigrum*		8	8	Beech-Maple
Black oak	*Quercus velutina*		40	24	Oak-Hickory
Black walnut	*Juglans nigra*		66	21	Beech-Maple
Black willow	*Salix nigra*		12	19	Floodplain forest
Blue ash	*Fraxinus quadrangulata*		3	20	Oak-Hickory
Box elder	*Acer negundo*	5	186	10	Floodplain forest
Butternut	*Juglans cinerea*		3	18	
Eastern cottonwood	*Populus deltoides*		28	12	Floodplain forest
Elm	*Ulmus spp.*	5	195	17	*
Flowering dogwood	*Cornus florida*		15	4	Beech-Maple
Green ash	*Fraxinus lanceolata*		18	14	Floodplain forest
Hackberry	*Celtis occidentalis*		98	15	Floodplain forest
Hickory	*Carya spp.*	7	240	14	*
Ironwood	*Ostrya virginiana*		31	6	Beech-Maple
Ohio buckeye	*Aesculus glabra*		1	4	Beech-Maple and Floodplain forest
Red oak	*Quercus rubra*		21	20	Oak-Hickory
Silver maple	*Acer saccharinum*		2	13	Floodplain forest
Sugar maple	*Acer saccharum*	11	397	15	Beech-Maple
Eastern sycamore	*Platanus occidentalis*		29	27	Floodplain forest
Tulip tree	*Liridendron tulipifera*		48	27	Beech-Maple
Oak spp.	*Quercus spp.*		18	24	*
Water beech	*Carpinus caroliniana*		40	6	
Water locust	*Gleditsia triacanthos*		1	12	Floodplain forest
White ash	*Fraxinus americana*	11	413	16	Beech-Maple
White oak	*Quercus alba*	6	208	23	Beech-Maple
White thorn	*Crataegus spp. ?*		5	8	Floodplain forest
Willow	*Salix spp.*		6	7	Floodplain forest
Yellow birch	*Betula nigra*		8	16	Floodplain forest
Total	**31 spp.**		**3620**		

* A genus that has species in many environments; thus with only the genus identified it is impossible to determine community associations

missed because of 1) the low density of the survey points, 2) the misidentification of tree species (or names that cannot be attributed to particular species), and/or 3) inaccessibility to portions of the landscape (Indiana examples include the omission of Bacon's Swamp in Marion County and Pinhook Bog in LaPorte County).

We also decided to use additional sources (primarily soil surveys), given the strong relationship between plant communities, soils, topography, and presettlement vegetation patterns. This approach, though not without problems, follows the earlier work of Lindsey and his colleagues (1965), Schaetzl and Brown (1996), and Lindsey (1997).

Marion County Soil Survey (1911)

The Marion County Soil Survey (Geib and Schroeder 1911) we used was produced in 1907 and published in 1911. In it, Geib and Schroeder described and mapped a series of soil associations according to soil properties with boundary delineation aided by information about historic vegetation communities and topographic relief. Attributes for each soil include soil type, soil code, soil texture (percentages of clay, silt, very fine sand, fine sand, medium sand, coarse sand, and fine gravel), and the associated potential natural vegetation (Table 2). We digitized the survey from an original copy and then integrated the soil attributes into the GIS. Wetland areas in the 1911 soil survey were mapped as Miami black clay loam or muck (Figure 2). By 1883 most of Marion County had been drained and tiled for agriculture (Brown 1883, Geib and Schroeder 1911). As a result, many areas that originally may have been wetlands probably were not identified as such in the 1911 survey. Our working hypothesis is that areas mapped as muck soils in 1907 were proving difficult to drain and may provide the best potential restoration sites.

Unique Areas Identified from Other Sources

We created the final layer for the pre-European settlement vegetation map using primary sources written during the period of European settlement. Some of these accounts provide descriptions of distinctive areas that are not identified in the GLO records or the 1911 soil survey (see examples in Table 3). These documentary sources are particularly important for wetland areas in the county that were quickly drained and destroyed. For example, in Oliver Johnson's account of pioneer life in Marion County, there is a description of "Round Pond Slough," an extensive wetland area located at the base of Crown Hill

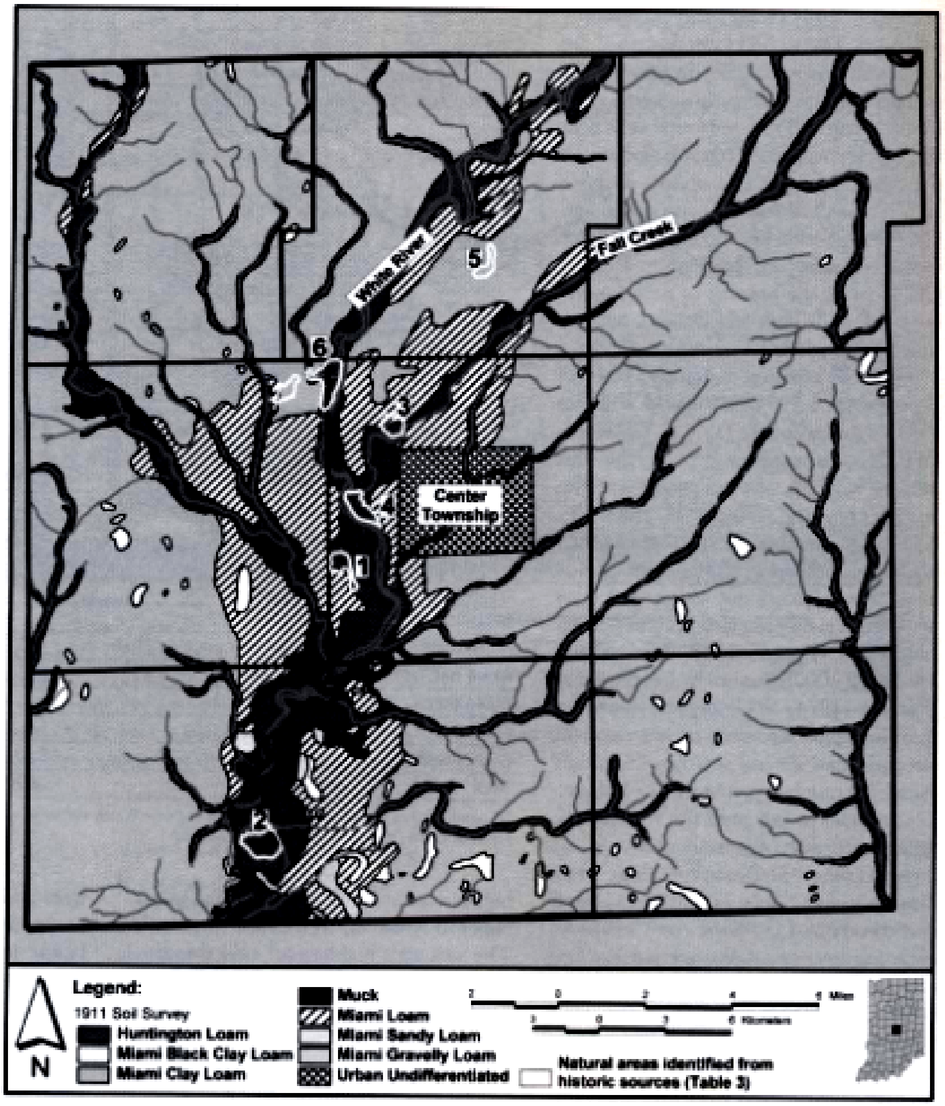

Figure 2. Soil associations from the 1911 Marion County soil survey and location of natural areas derived from other historic sources.

(Johnson 1978). This is the only known reference to this wetland. The only report of a wet prairie in Marion County is found in an early account of the geology of Marion County (Brown 1883). Old maps of the Indianapolis area show the original position of Fall Creek and an extensive wetland complex located at the confluence of Fall Creek and White River (Matthew 1981). For this map layer, all locations mapped by primary accounts are numbered, with the number corresponding to a reference that details the source of the information used in determining the location of the site (Figure 2 and Table 3).

Contemporary Vegetation Cover (1997)

The present distribution of forest cover and open ground in Marion County was compiled using: 1) a 1997 Systeme Pour l'Observation de la Terre (SPOT) satellite image; 2) Marion County zoning data to delineate urban and agricultural areas; and 3) the National Wetlands Inventory (U.S. Fish & Wildlife Service, NWI, 1990).

SPOT Imagery

We decided to use multi-spectral imagery from the SPOT satellite in this study because it offers the highest spatial resolution of any multi-spectral imagery currently available (in 1998) from a space-borne platform, and the geographic extent of an image is more than sufficient to cover the area of Marion County. The SPOT XS image was collected on July 27, 1997. Preprocessing of the imagery was conducted by SPOT Image Corporation to the "3a" level, which includes both radiometric and geometric corrections. The image was geo-referenced to the UTM coordinate system, zone 16 north, using the NAD27 datum, and Clarke 1866 spheroid.

We used an unsupervised classification technique to create a land use/land cover map of the study region from the SPOT image. Unsupervised classification is a data aggregation technique commonly used in remote sensing to group pixels in a digital image into homogeneous groups known as spectral clusters (Jensen 1996, Lillesand and Keifer 2000). The grouping is based on similarities in the way electromagnetic energy interacts with the surface features as captured by the sensor. This interaction is a function of the type and condition of land cover present in the area represented by each pixel. More simply, pixel grouping is based on land cover characteristics. The algorithm generated 50 spectral clusters, each of which was assigned to one of ten land use/land cover classes by comparing their location in the original image to independent data sources, including aerial photographs and topographic maps. Of interest here are two classes: medium to dense woodland and low-density woodland (Figure 3).

Marion County Zoning Data

The coarse resolution of the satellite imagery relative to the high spatial frequency of land cover changes in urban and suburban environments can cause inaccuracies in satellite-based assessments of urban land cover. Given the sensor's spatial resolution (20 m x 20 m in the case of SPOT XS data), unless the pixel falls on a homogeneous area of land cover, the spectral reflectance is a function of all land cover types that occur within the pixel. In addition, errors in land cover mapping can result from similarities in spectral reflectance properties of different land use/land cover types. For example, from the perspective of the satellite, older residential areas with relatively mature and dense tree canopies can exhibit similar or identical spectral reflectance characteristics as "true" forests. Incorporating ancillary GIS data can help overcome such problems.

In our study, we used zoning data to differentiate urban and agricultural areas, and to delineate urban, suburban, commercial, industrial, and special use (park)

Table 2. Soil classification system from the 1907 Soil Survey of Marion County.

Soil Type	# of Acres	Percent	Original Survey Notes
Miami clay loam	188,672	75.9	Uplands, original timber included: beech, oak, maple, elm, ash, and walnut
Huntington loam	31,040	12.5	Alluvial soil (poorly drained) original timber included ash, elm and sycamore, with some hickory, oak, and beech
Miami loam	24,768	10.0	Upper terrace soil between the Huntington loam and the Miami clay loam
Miami black clay loam	2,880	1.1	Located in small basin-like depressions throughout the uplands. These areas range in size from 5 to 160 acres. Prior to drainage these were areas of swamp and marsh.
Miami gravelly loam	576	0.2	Small areas of gravelly well drained ridges and hills. Located in upland areas
Miami sandy loam	512	0.2	Small patches of well-drained areas
Muck	256	0.1	Relic peat bogs, areas of swamp and marsh

Table 3. Natural areas in pre-settlement Marion County identified from sources other than the GLO Survey of Marion County (1820-1822).

Number	Source	Described Feature
1	Brown (1883)	Wet prairie or marsh complex, "located on the farm of Fielding Beeler, on the Vincennes railroad, two miles from the city."
2 & 6	Geib and Schroeder (1911)	Relic peat bogs, "one lies five miles due west of Southport, the other the same distance to the northwest."
3	Johnson (1978)	Round Pond, swamp located at what is now the intersection of Michigan Road and I-65.
4	Matthew (1981)	Marsh complex at the confluence of Fall Creek and White River from old maps of the campus area.
5	Roettger (1994)	Bacon's Swamp

areas, amongst others, within the county. This information is maintained by the Department of Metropolitan Development, and was digitized by Indianapolis Mapping and Geographic Information Systems (IMAGIS).

National Wetlands Inventory Maps

We also used a 1990 National Wetlands Inventory (NWI) to delineate remaining wetlands within Marion County. We modified the standard NWI map for Marion County to show only the naturally occurring wetland areas. We removed all areas described by the modifiers h, for diked or impounded, or x, for excavated (Cowardin and others 1979) (Figure 3).

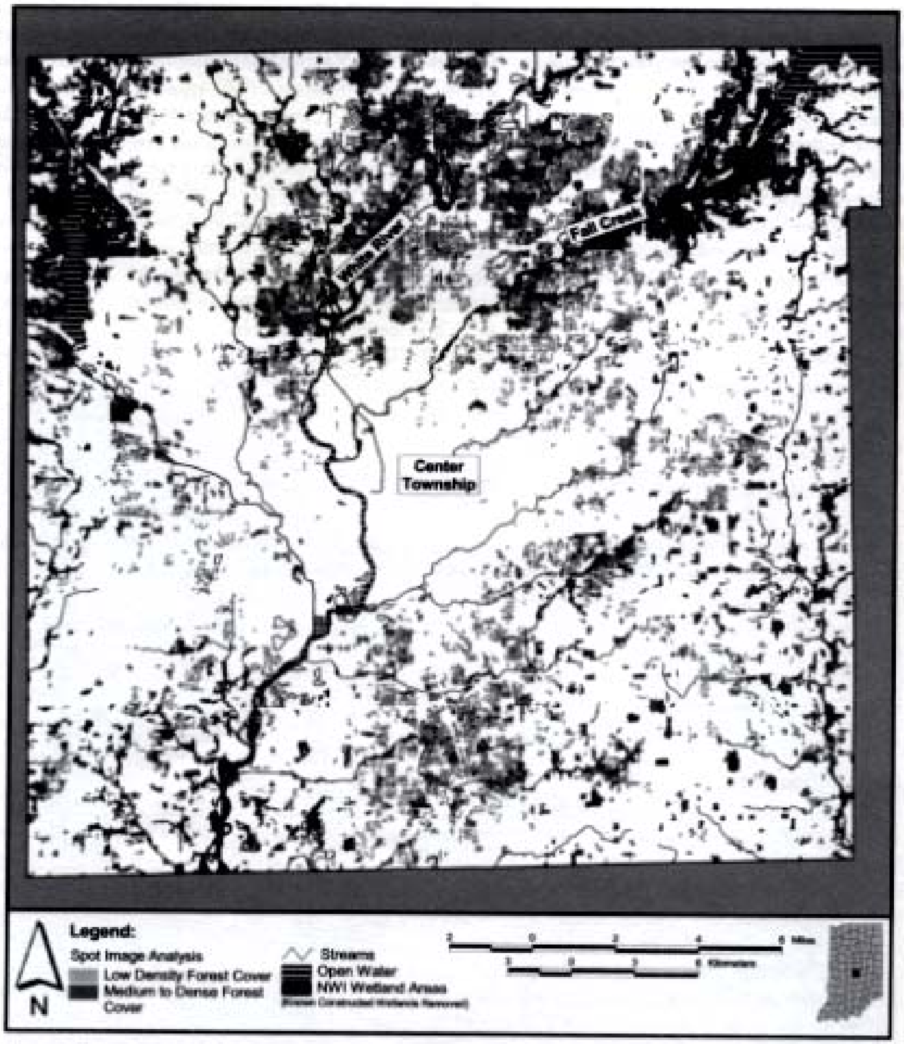

Figure 3. Current areas of medium to dense forest cover based on classification of the SPOT image and location of NWI wetland areas.

Results and Discussion

Pre-Settlement Vegetation Cover

Using classification schemes developed by Lindsey and his colleagues (1965) and the IDNR, Division of Nature Preserves (1980), we identified six major plant community types (beech-maple forest, oak-hickory forest, wet-mesic depressional forest, wet-mesic floodplain forest, swamp forest and marsh). Forest originally covered about 98 percent of Marion County. The rest of the area was either open water or small patches of prairie. Mesic beech-maple upland forest covered about 76 percent of the county, with the dominant tree species in this community being American beech and sugar maple (*Acer saccharum*). Other important trees in this association were basswood (*Tilia americana*), black walnut (*Juglans nigra*), hickory (*Carya* spp.), red oak (*Quercus rubra*), white oak (*Q. alba*), and white ash (*Fraxinus americana*) (Petty and Jackson 1966). Small areas of oak-hickory forest were located along drier ridges and slopes, particularly in the northwestern and northeastern parts of the county (Brothers 1994) (Figure 1).

Small areas of wet-mesic depressional forest were found throughout the county. The distribution of this community type is best seen by looking at the areas mapped as Miami black clay loam during the 1911 soil survey of Marion County (Figure 2).

Floodplain forests were most extensive along the White River and its major tributaries (Geib and Schroeder 1911, Brothers 1994). The most commonly noted trees were box elder (*Acer negundo*), green ash (*F. lanceolata*), hackberry (*Celtis occidentalis*), silver maple (*A. saccharinum*), and sycamore (*Platanus occidentalis*). Other important trees were cottonwood (*Populus deltoides*) and elm (*Ulmus* spp.). On the floodplain terraces and narrower floodplains, more mesic species increased in importance. These included beech, black walnut, and red and white oak (Brothers 1994).

The swamp forests held standing water longer than the floodplains and occurred near the White River, on or near the floodplain, and scattered throughout the uplands in depressions. The distribution of these forests can still be inferred by looking at the soil associations in these areas (Sturm and Gilbert 1978). Dominant trees in the swamp forests were swamp white oak (*Q. bicolor*), bur oak (*Q. macrocarpa*), box elder, elm, green ash, hackberry, and willow (*Salix* spp.). Other common species were sycamore and silver maple (Brothers 1994).

We identified several potential wetland areas using the GLO survey of Marion County (1820-1822). These areas ranged from seasonally flooded depressional areas to marsh. In the surveyor's notes, 13 sections are described simply as wet, and 29 sections are described as swamp or swampy. Brown (1883) described the only area actually listed as marsh.

Use of GIS to Enhance Historic Interpretation of Forest Cover

For several important genera, most notably hickory, some oaks and the elms, the original surveyors did not distinguish between species. A comparison of the GLO survey records with topography (defined by IMAGIS 1979 spot elevation data and a digital coverage of FEMA delineated floodplains) can, however, provide valuable insight into the environment where some species were found and also into relative species abundance in the predisturbance landscape. For example, the GLO surveyors recorded 240 hickories in their survey of Marion County. Some hickory species—bitternut (*Carya cordiformis*) and shellbark (*C. laciniosa*)—are normally found on floodplains and in more mesic sites. Of these species, only bitternut is common in the county, while shellbark is uncommon to rare (Deam, 1932). Other species—shagbark (*C. ovata*), pignut (*C. glabra*), and mockernut (*C. tomentosa*)—are known in central Indiana to grow preferentially on south-facing, drier hillslopes. Of these, mockernut is rare in central Indiana (Deam 1932) and shagbark tends to preferentially grow on terrace slopes. Thus it is likely that most of the 27 hickory trees located on the alluvial floodplains (Figure 1) were bitternuts, and by inference, most of the 203 hickories listed in upland areas (Figure 1) would have been pignuts. Although these inferences are certainly generalizations, they do allow us to make approximations from the limited primary data. This can be particularly valuable with regard to the more mesic floodplain species.

Table 4. Fraction of zoning districts categorized as medium to dense forest. Derived by overlaying SPOT medium and dense forest spectral classes on Marion County Department of Metropolitan Development zoning database (see text).

Zoning district	% county covered by zoning district	% of zoning district covered by medium or dense forest cover as defined in this study
Suburban Residential	54.82	32.11
Urban Residential	9.76	19.36
Central Business District	0.30	0.00
Other Commercial	8.14	7.47
Airport	1.39	0.29
Hospital Districts	0.48	7.14
Urban Industrial	3.15	4.14
Suburban Industrial	6.71	7.71
Interstate	1.93	3.35
Special Use (Public)	4.42	20.35
Special Use (Commercial)	3.70	27.07
Park Districts	4.84	34.02

One of the more valuable products of this work was a large-scale map on which all the different historic sources are compiled. Unfortunately, the detail of this map is not reproducible at a scale we could include in this paper.

Contemporary Forest Cover

Classification of the 1997 SPOT imagery shows medium to dense forest canopy across about 13 percent of the County (Figure 3). More than five percent of this forested area is preserved in two relatively contiguous tracts—Eagle Creek County Park and Fort Harrison State Park (Figure 4). The forest cover not associated with those two parks is found primarily along White River and its tributaries and in older residential areas. Forest cover is almost absent from the southern parts of the county, with the exception of the White River valley (Figure 3).

We were able to gain greater insight into the distribution of the remaining forest cover within the city and its relation with land use by overlaying the Marion County zoning map on the map of current forest cover (Table 4). The importance of parks in preserving areas of high forest cover is clearly evident, as is the role of older historic residential areas to the north of the city. Areas of medium to dense tree cover in suburban residential zones average 32 percent. This value falls to less than 20 percent in urban residential neighborhoods, and there is effectively no continuous tree cover downtown (Table 4).

To gain greater insight into the quality of the present day forest cover, we used the SPOT data and calculated the normalized difference vegetation index (NDVI) using an algorithm that takes advantage of the unique spectral reflectance properties of vegetation to differentiate it from other land cover types. Figure 4 shows NDVI across the area of interest. The original values range between +1 (high) and -1 (low). In Figure 4, these values were stretched using standard procedures to an unassigned 8-bit scale (0-255). From the image, greater biomass is evident in the parks and the older residential neighborhoods on the north side of the city. It should be noted that while NDVI is widely accepted as a measure of plant biomass and vigor, a number of factors not related to vegetation are known to influence NDVI values (incident solar radiation, radiometric response

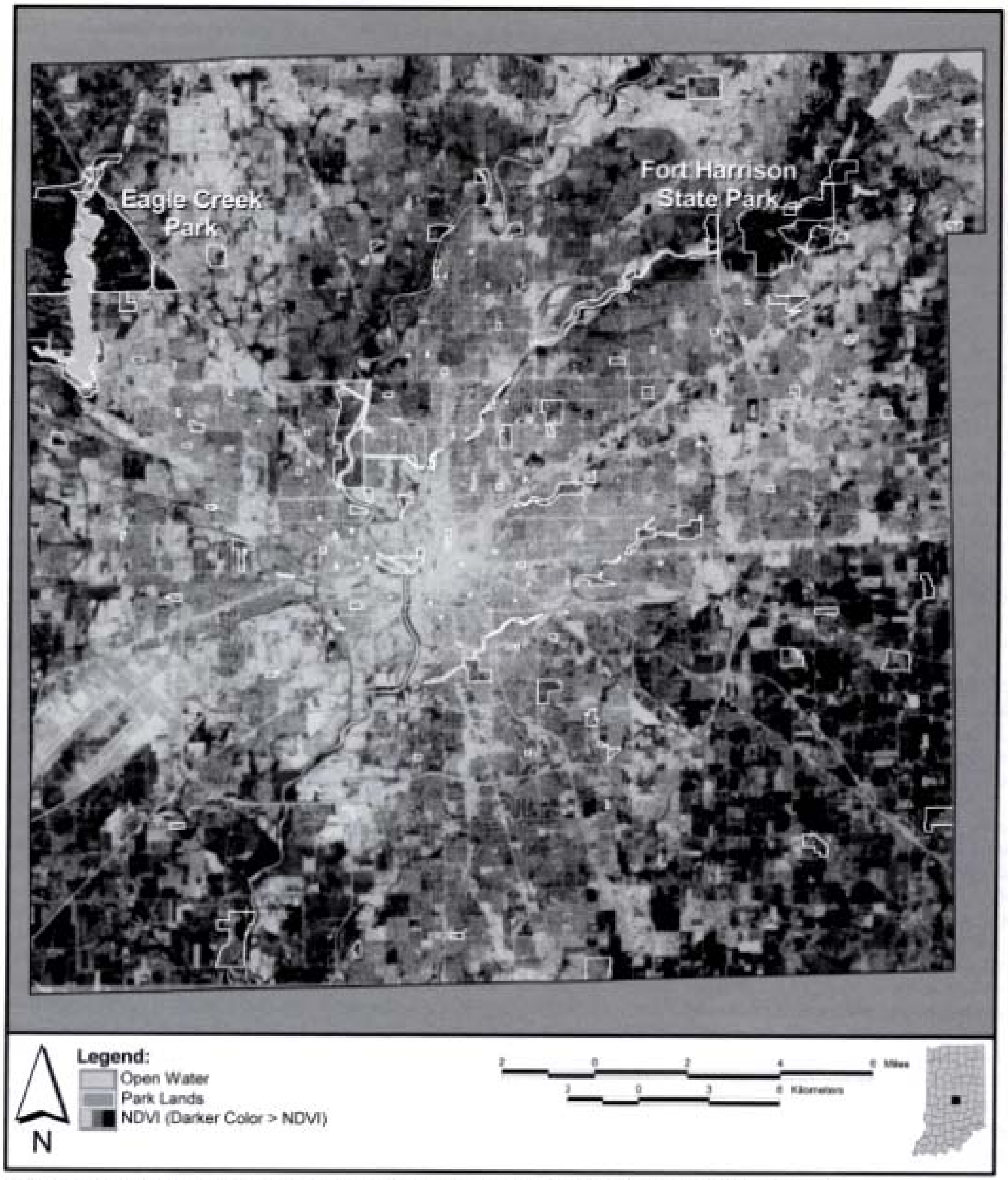

Figure 4. NDVI with FEMA delineated floodplains (1988), wetlands, and location of park properties in Marion County.

characteristics of the sensor, and off-nadir viewing). In addition, relationships between NDVI values and vegetation biophysical characteristics may only be valid within a particular vegetation cover type; that is, similar NDVI values may be observed within forest and herbaceous vegetation cover types.

Observations and Conclusions

One of the primary goals of this work was to provide the Indianapolis Parks Department with a means to identify areas in the county with the potential for restoration. From the outset it was recognized that few, if any, areas in Marion County had escaped modification, but park stewards and researchers hoped that this work would help identify the locations of some fragments of the natural landscape.

Parks and city staff have used the findings in planning processes related to land management and acquisition and to educate the public about land use change and canopy cover. One of the first uses of the modern forest cover map was to help identify high quality woodlots throughout the county. To accomplish this, Indianapolis Parks Department and the Center for Earth and Environmental Science at IUPUI overlaid the current forest coverage map on 1941 aerial photography to identify potential areas of high quality woodlots. Woodlots identified in 1941 that still appear as forest in 1997 are now being field-checked to determine their overall quality. As high quality sites are identified, they are ranked and placed on a potential acquisitions list. This list is incorporated by reference in other local planning documents.

Indianapolis Parks staff and volunteers now are field-checking the areas of muck soils mapped in 1907 to evaluate whether they might be potential sites for restoration. To assist with this process, a map was created that shows the surveyors' narrative comments from the GLO survey, areas of muck soil as mapped in 1907, and current major roads.

The city of Indianapolis has also used the modern forest cover map to help foster an interest in urban forestry in the city. Staff in the Office of Environmental Services have created a Web site to help educate the general public about the value of urban forests. The Web site allows residents to view forest cover in either their township or their watershed (City of Indianapolis 2001).

From a methodological perspective, our results can be replicated relatively easily elsewhere for comparatively low cost. Use of historic soils data to infer vegetative associations has a number of limitations, but is a pragmatic approach to framing debates and decisions about restoration. Similarly, mapping witness trees is a practical, cost-effective way to corroborate informed judgments about the original species distribution. Use of satellite imagery is not expensive, is becoming cheaper, and provides a set of base maps and data that can be used in a number of different applications. GIS provides an efficient means to integrate spatial data and to draw inferences from information from disparate sources.

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