Analyzing Forest Landscape Restoration Potential: Pre-settlement and Current Distribution of Oak in the Northwest Wisconsin Pine Barrens

Abstract

Ecosystem restoration and management requires knowledge of the species composition, ecological processes, and structure of natural landscapes. Current forest landscapes of Wisconsin are the result of over a century of human use. Certain ecological processes, such as fire, cannot be studied in the current human-dominated landscape. Our study objective was to reconstruct the historical, large-scale pre-European landscape of the Pine Barrens in northwestern Wisconsin and to compare the extent and abundance of the oak component to its current importance. Our questions were (1) does the current distribution of oak resemble pre-settlement conditions and (2) did oak savannas exist at pre-settlement times, which would indicate a high frequency but low intensity fire disturbance regime. We used a species-level satellite image classification to map the current distribution of oak. The pre-settlement conditions were reconstructed using the U.S. General Land Office (GLO) surveyor notes dating from 1847–59 in a geographical information system (GIS).

Our results indicate that oak increased in the Pine Barrens landscape over the last 150 years. The increase is particularly strong where nineteenth-century surveyors mentioned oak understory. Fire suppression may have contributed to the oak increase by permitting these understory oaks to reach canopy height. Oak savannas were not widespread in the pre-settlement landscape, but likely did exist in the south-central part of the Pine Barrens, where larger, dispersed bur oaks were noted by the surveyors. Our study demonstrates the value of the GLO data for the broad scale reconstruction of pre-settlement vegetation and disturbance characteristics. These historical data can provide managers with additional information about ecosystems and can assist in restoration management.
Ecosystem restoration and management requires knowledge about the species composition, structure, and processes of the system under consideration. This poses a challenge, because very basic information can be difficult to obtain for current landscapes in Wisconsin due to changes imposed by over a century of land use by European settlers.

Our study focuses on the Pine Barrens region in northwestern Wisconsin (Figure 1). The Wisconsin Department of Natural Resources (DNR) chose this ecoregion as the first in Wisconsin to be assessed as a regional ecosystem. In 1993, the DNR workshop “The Future of Pine Barrens in Northwest Wisconsin” (Borgerding et al. 1995) summarized current understanding of this ecosystem and identified some information gaps regarding the structure and composition of the pre-settlement forest landscapes. For example, the amount of open habitat and forest density present prior to 1840 was a point of discussion. This question is important for ecosystem management of the Pine Barrens; an answer requires study of historic data sources because of ecosystem changes during the last 150 years of European settlement.

The Pine Barrens ecosystem is located on a glacial outwash plain with extremely coarse and nutrient-poor sandy soils. The excessive drainage makes the region prone to drought and frequent forest fires (Curtis 1959). In pre-settlement times, these factors favored tree species such as pine and oak that are adapted to frequent fire. Jack pine (Pinus banksiana) has serotinous cones that are

![Figure 1. The counties of the Pine Barrens region in northwest Wisconsin.](image-url)
sealed with resin. High intensity fire melts the resin and opens the cones, releasing the seeds. Regeneration usually follows on the exposed mineral soil. Mature red pine (Pinus resinosa), bur oak (Quercus macrocarpa), and to a degree white pine (P. strobus), are protected by thick bark from damage by less intense surface fires. Northern pin oak (Q. ellipsoidalis) and bur oak are able to resprout if their stems are killed by fire (Curtis 1959).

Very few descriptions exist of the Pine Barrens vegetation before European settlement during the second half of the nineteenth century. Geological surveyors wrote that "in the 'barrens' . . . the trees are either scrub pine (P. banksiana), or black-jack oaks (Q. ellipsoidalis), averaging in diameter about three or four inches and in height not over fifteen feet. In some places . . . the trees are at considerable distances from each other" (Sweet 1880). Some portion of the Pine Barrens "are covered with scrub pine to the exclusion of all else save underbrush. . . Other areas are covered with burr, black, and even white oak bushes, with occasional trees of these species" (Strong 1877). Finley, in his analysis of the General Land Office (GLO) surveyor notes, classified the region as "jack pine, scrub (Hill's) oak forests and barrens" (Finley 1951).

All these sources describe forests of low density that contained pine and oak to varying degrees. However, these sources do not provide details about spatial variability of forest composition and structure across the Barrens landscape. Did soil differences affect the pattern of forest structure? Did meso-climatic differences (e.g., the lake effect in the North) result in different forest types? Were the southern parts of the Barrens, being closer to the prairie border, more open?

These questions are highly relevant for ecosystem management, but answering them is difficult. Changes during the last 150 years due to logging, farming, and forestry make it difficult to assess what the pre-settlement ecosystem looked like and how it functioned in relation to past disturbance regimes.

Logging, starting around 1850, focused first on white pine and later red pine (Murphy 1931). Loggers were followed by settlers because the sandy soils were easy to plow (Vogl 1964). Intense forest fires increased due to the slash from the logging operations and also opened the forests. Around 1910, jack pine logging began after technology became available to use jack pine wood for pulping. At this time, the combination of logging and farming probably created more open habitat than ever before. In the 1930s, the economic depression and the depletion of the inherently nutrient-poor and droughty soils caused many farmers to abandon their land. Much tax-delinquent land became the starting point for creating county forests, timber industry holdings, and the Chequamegon National Forest (Vogl 1964). Civilian Conservation Corps workers planted large tracts with jack pine, and the Wisconsin Conservation Department began fire suppression programs. These developments created the present-day forest, which may be much denser than before European settlement.

Our research questions are: what was the relative importance of oak throughout the Pine Barrens, and did oak savannas and woodlands exist in the Pine Barrens before the advent of European settlers? How did the oak component in the landscape change since European settlement?

Savannas are best defined structurally; they have less canopy coverage than forest. Any distinct boundary between savannas and forests is somewhat arbitrary; we follow Curtis (1959), who suggested less than 50% canopy coverage as a threshold to define savanna.
Currently, oak is common in the region, especially in the northern and southern parts. Restoration efforts in the Pine Barrens have focused on open Barrens habitat (Vogl 1964, Vora 1993). Our study investigates whether the existence of oak savannas in pre-settlement times suggests we should discuss their restoration also.

We analyzed the Pine Barrens pre-settlement vegetation using the U.S. General Land Office survey notes in a geographical information system (GIS). We compared these data with the current forest cover as mapped from Landsat satellite imagery. Because the GLO data were not recorded for scientific purposes, they contain some bias. For instance, some surveyors favored certain species over others as witness trees. In some areas, different surveyors mapped the township boundaries (exterior lines) and the township area (interior lines). Nevertheless, the GLO data set is one of the best data sets available for reconstructing pre-settlement vegetation (Galatowitsch 1990, Manies 1997) and for studying pre-settlement vegetation in relationship to soils (Whitney 1982, Delcourt and Delcourt 1996), fire (Lorimer 1977, Kline and Cottam 1979, Grimm 1984), and windthrow (Canham 1984). A number of studies used GLO data to examine landscape changes (Stearns 1949, Mladenoff and Howell 1980, Iverson and Risser 1987, Iverson 1988, White and Mladenoff 1994, Whitney 1994). Studies that analyzed the GLO data on an individual witness tree level usually examined areas no larger than a few townships (Thomson and Fassett 1945, Delcourt and Delcourt 1996). For some Midwestern states, generalized maps of the pre-settlement vegetation have been generated (Finley 1951). However, these maps required a classification of the witness tree data into general cover classes, thus losing much detail.

Methods

**GLO Data analysis**

Wisconsin was initially surveyed around the middle of the nineteenth century. The land was divided into townships (6 x 6 miles), sections (1 x 1 mile), and quarter-sections (0.5 x 0.5 mile) so that it could be sold to homesteaders and logging companies. To establish the location of each township, section, and quarter-section, survey posts were placed at each corner (all referred to as corners in the following). The surveyors marked 2–4 witness trees in the vicinity of each corner. In their journals, the surveyors recorded the species, diameter, and distance from the corner for each tree. Sometimes, they also described understory vegetation.

Our study is one of the first to analyze GLO witness tree data in a GIS for a large ecoregion. The advantage of the GIS-based approach is that a high level of detail can be maintained for extensive areas. The data set is part of a larger database of the entire state of Wisconsin currently under development at the Department of Forest Ecology and Management at the University of Wisconsin-Madison in cooperation with the Wisconsin DNR (Manies 1997). For our analysis, we used only the witness trees at township, section, and quarter corners and disregarded trees along section lines and at so-called meander corners, where survey lines intersected water bodies. The data set contains point information for 5,086 corners with a total of 11,153 trees in the Pine Barrens. For each corner, we calculated the mean distance traveled from the corner to record the witness trees. We did not interpolate between the corners to derive forest type polygons, but rather analyzed the complete data set.
Satellite image analysis

To compare the GLO data with the current vegetation cover, we utilized a species-level satellite image classification previously derived for northwest Wisconsin (Wolter et al. 1995). A number of studies have used satellite imagery to map forest cover (Hopkins et al. 1988, Moore and Bauer 1990, Hall et al. 1991, Bolstad and Lillesand 1992, Woodcock et al. 1994). Image processing software uses reflectance differences between tree species to classify raw satellite data into land cover maps (Lillesand and Kiefer 1994). The distinction of deciduous from coniferous forest usually can be achieved with an accuracy greater than 85%. However, differentiating among deciduous species is difficult and less accurate when only a single satellite image is used. For instance, the reflectance of sugar maple (Acer saccharum), trembling aspen (Populus tremuloides), and red oak (Q. rubra) are not different during the peak of the growing season. Single-species classification accuracy can be improved by analyzing a suite of images throughout the time of senescence and leaf flushing (Wolter et al. 1995). Peak fall colors for red oak are about two weeks later than for sugar maple. In spring, trembling aspen leaves out about one week earlier than other hardwoods. Satellite imagery captured at these different points can identify the distribution of various species. Using a total of five satellite images, Wolter et al. (1995) were able to classify nineteen types of forest cover and eight other land cover types with an overall accuracy of 83.2%.

In the satellite image classification, red oak occurs predominantly in the northern half and pin oak in the southern half of the Pine Barrens (Plate 2b; see p. 201). For red oak, the producer’s accuracy of the classification was 86.7% and for pin oak 81.6%.

Producer’s accuracy indicates what percentage of the pixels on the ground was correctly identified in the classification. The user’s accuracy was 84.8% for red oak and 100% for pin oak. User’s accuracy indicates what percentage of the pixels in the classification is actually that species on the ground. For example, all pin oak on the map is pin oak on the ground, but 18.4% (100%–81.6%) of all pin oak on the ground was mapped as other classes in the image classification. The satellite image classification does not identify bur oak because there were not enough pure stands of this species to use as references for the classification algorithm (Wolter et al. 1995).

Data integration

Examining landscape changes by comparing GLO data to a satellite image classification is not straightforward. The two data sets have very different data capture methods and spatial resolutions. The GLO surveyors mapped points at 0.5 mile distances. They sampled between one and four trees, commonly two, in the vicinity of the corner. The species chosen were not necessarily the dominant canopy species. In contrast to the GLO data, the satellite image classification contains a continuous grid with a 28.5 x 28.5 m pixel size. Each pixel is classified according to its dominant canopy species, thus containing only one tree species.

Processing was required before the two data sets could be compared. Each GLO corner location falls within a single pixel of the satellite image classification. However, the surveyors chose witness trees from a larger radius than 14.25 m, which is half of a pixel (28.5 m). Therefore, we recorded presence or absence of oak in the satellite classification in circles, or buffers, around each corner. This operation was performed
three times with different buffers (5, 9, and 21 pixel) to evaluate the effect of different buffer sizes on our analysis (Figure 2). We re-classified the GLO data to represent the presence or absence of oak at each corner, thereby making the two data sets compatible. In the integration of GLO data and the current classification, each corner was classified as either (1) oak present only in the GLO data, (2) oak present only in the satellite image classification, (3) oak present in both data sets, or (4) oak not occurring.

For a general comparison of data sets, we calculated the relative occurrence of oak in comparison to other tree species in the GLO data set and the satellite image classification of single pixels. In the GLO data we summarized how often the surveyors found each tree species and calculated percentages for each species. The calculation of relative occurrence of tree species in the satellite image classification was based only on forest classes because classes such as water or settlements were not recorded in the GLO data, but classified in the satellite image. The comparison of relative occurrences is independent of buffer sizes.

Results

GLO data

The distribution of pre-settlement forest vegetation derived from the GLO data suggests that the Pine Barrens was not a homogenous region (Plate 1a; see p. 200). The northern part in the Bayfield Peninsula was dominated by red pine, intermixed with white pine, red oak, and jack pine.

The central part of the Barrens in Douglas County was covered predominantly by jack pine. Red pine occurred largely along the edges of the outwash plain or in the vicinity of natural firebreaks such as lakes. The central part also contained a 5-km long patch where no trees were recorded by the surveyors. Their field notes mention that charred sticks were used as corner posts in this patch, indicating a recent fire.

The southern part of the Barrens, in western Burnett and in Washburn Counties, was characterized by a north-south gradient, with jack pine dominating in the north and red pine, oak, and white pine dominating the south. Pin oak and bur oak often occurred.

Figure 2. Different buffer sizes used to estimate oak presence around corners in the satellite image classification.
close to lakes, which are particularly abundant in this area (Plate 1b).

The extreme southwestern part of the Barrens, in southwest Burnett and northwest Polk Counties, showed a similar north-south gradient, though the surveyor of the townships in Polk County (H. Maddin) did not distinguish among pine species. Bur oak was the most common oak, occurring along the valley of the St. Croix River and the edge of the outwash plain. Corners where no trees could be found were located in marshy areas.

Oak diameters in the GLO data were not randomly distributed across the Barrens (Plate 1c). In the north and central Barrens, most of the oaks were small (10–30 cm diameter), with some trees as large as 50 cm. The largest oaks, up to 85 cm in diameter, were recorded in the southern and southwestern parts, usually in close vicinity to lakes and streams.

A characteristic of savannas is their low tree density. Large distances between a corner and its witness trees in the GLO data indicate low relative tree density (Plate 2a). The largest distance class (251–2000 m) represents corners where surveyors found very few trees due to recent fires or marshes. The distribution of these points follows no clear pattern except in one patch in the central Barrens mentioned above. The corners in the smaller distance classes (<25–250 m) demonstrate a strong northeast-southwest gradient of the forest densities. Forest density was highest in the northeast and much lower in the southwest of the Pine Barrens.

**Comparison of GLO and satellite data**

The abundance of oak region-wide increased between pre-settlement times and today. The apparent amount of increase is partly dependent on the buffer size used for detecting oak in the satellite image classification.

<table>
<thead>
<tr>
<th>Buffer size (# of Pixel)</th>
<th>21</th>
<th>9</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oak only in 1850</td>
<td>226</td>
<td>304</td>
<td>343</td>
</tr>
<tr>
<td>Oak only in 1987</td>
<td>1,539</td>
<td>1,050</td>
<td>819</td>
</tr>
<tr>
<td>Oak in 1850 and 1987</td>
<td>259</td>
<td>181</td>
<td>143</td>
</tr>
<tr>
<td>Never oak</td>
<td>3,057</td>
<td>3,548</td>
<td>3,779</td>
</tr>
</tbody>
</table>

Larger buffers will always result in a greater increase (Greig-Smith 1983). However, even with the most conservative five-pixel buffer, the oak increased from 1850 to 1987 by 198% (9 pixel: 253%; 21 pixel: 371%).

The absolute number of corners where oaks occurred only in 1987 increased by 720 (48%) when the buffer size is increased from 5 to 21 pixels (Table 1) and conversely, the number of corners without oak decreased by 722 (19%). For corners with oaks in the GLO data, 53% also had oak in the satellite image classification when calculating a buffer of 21 pixel, but only 29% when a buffer of 5 pixels was used.

Many changes in oak occurrence are rather local (Plate 2c). We present only the increase estimated with the largest buffer size; maps from the two smaller buffer sizes reveal the same areas of oak increase. Especially in the south, there are many cases where a given corner contained oak only in the GLO data and the neighboring corner had oak only in the satellite image data. These changes are most likely due to local patch dynamics.

In the north, there are fewer corners where oak occurred only at pre-settlement times, and many of the corners contained oak in both data sets. There is also a strong increase in oak throughout Bayfield County. The central part of the Barrens experienced the smallest increase of oak (Figure 3). The areas where
oak was mentioned in the understory from GLO surveys are the same areas where a strong increase of oak occurred by 1987.

The relative occurrence of oak versus other cover types as represented in GLO data and the satellite image classification of the Pine Barrens region as a whole agreed with the results obtained with the buffer analysis (Figure 4). Out of the total area covered by forest, oak and pine combined occupied about 62%. However, oak alone increased from 8 to 23%, and pine decreased correspondingly.

Discussion

Ecosystems are dynamic entities, and studying them at only one point in time (e.g., the GLO survey date) provides an incomplete picture. Disturbance events, like large crown fires, alter the environment drastically over short time periods. A study that analyzes only data taken before the fire is likely to underestimate the influence of fire, while a study based on data captured after the fire might carry the opposite bias.

Furthermore, ecosystems adapt to long-term
environmental changes. Climate has changed throughout the Holocene, and with it, vegetation cover has changed (Davis 1986, 1993, Webb et al. 1993). Predicting how the vegetation would have changed since 1850 in the absence of European settlement is problematic.

The pre-European settlement vegetation was not entirely natural or free of human alterations. Native Americans deliberately burned parts of the landscape to increase berry production and hunting opportunities (Murphy 1931), but the magnitude of ecosystem changes by Native Americans is difficult to assess, particularly in northern forest regions (Lewis and Ferguson 1988, Clark and Royall 1996).

The GLO data are not equivalent to the potential natural vegetation. When analyzing the pre-settlement vegetation, these limitations have to be kept in mind. We do not consider the vegetation cover suggested by the GLO data as a necessary goal for resource managers, nor do we advocate restoration of the landscape to a specific point in time. However, the pre-settlement vegetation cover was certainly less altered by humans than the current forest cover. Analyzing the pre-settlement vegetation provides a unique opportunity to study ecosystem composition, structure, processes and variability in relatively more natural conditions. Pre-settlement vegetation data are highly relevant where ecosystem management is being attempted, because they provide evidence of vegetation patterns at another point in time and under different disturbance regimes.
The importance of surveyor bias contained in the GLO data has been discussed in various publications (Bourdo 1956, Delcourt and Delcourt 1974, Grimm 1984, Iverson and Risser 1987). Opinions range from "the information recorded by the surveyors provides an unbiased sample of vegetation cover as it existed in pre-settlement days" (Vogl 1964, p. 161) to much more conservative analyses of surveyor bias and attempts to quantify it (Bourdo 1956, Delcourt and Delcourt 1974, Manies 1997). The species recorded at a given location may have been a singular occurrence. Also, absence of a tree species does not necessarily indicate that the species was absent from the landscape. The ability of surveyors to identify tree species correctly is variable. In Polk County, in the southern Barrens, the surveyor (H. Maddin) recorded only 'pine' without further distinction. The occurrence of black oak (Quercus velutina) in the Pine Barrens is very unlikely, because its northern range does not reach this region. However, several surveyors recorded black oak (Plate 1b), probably referring to the black oak group that contains northern pin oak, northern red oak, and black oak (Curtis 1959). The raw information of the surveyor notes needs to be interpreted carefully before ecological conclusions can be drawn.

The scale of the GLO data limits its minimum mapping resolution (Delcourt and Delcourt 1996). This makes analysis of small areas, such as single townships, questionable. However, the resolution of the GLO data appeared to be adequate to interpret regional trends at the scale of the Pine Barrens landscape (450,000 ha). Regional trends can be concealed when data are classified and aggregated before the analysis. The use of a GIS allowed us to handle the large amount of detailed information, without classifying it initially. This was essential for our approach to compare species occurrence at each section corner.

Despite potential problems, the GLO data contain a vegetation sample of tremendous value. The data were collected during a relative short time period. The survey of the Pine Barrens was completed in twelve years (1847–1858), and 68% of the data were collected in two years (1855–1856). During these few years the Pine Barrens landscape presumably did not experience major changes. The brief survey period of the Barrens ensures that spatial vegetational differences reflect environmental gradients and not temporal changes.

The data collection was standardized, and single surveyors covered large areas. For instance, three surveyors (H.C. Fellows, E. Sears, and A.C. Stuntz) surveyed 74% of all corners in the Pine Barrens. The small number of surveyors minimizes the impact of personal bias.

The sampling scale of the GLO survey is uniform, which makes regional comparisons possible. There are no other detailed pre-settlement vegetation data available for large regions. The value of the GLO data for vegetation analysis, despite all constraints, becomes apparent when examining the species composition of the Pine Barrens (Plate 1a). The occurrence of red pine and oak throughout the Barrens is associated with soil, topographic, and hydrologic features that influenced fire patterns. Slight differences in soil quality, topography, and hydrology are reflected in the GLO data. Detailed soil maps for the Pine Barrens are not available, but the mapping of Landtype Associations by the Wisconsin DNR provides a coarse picture of soil productivity (Figure 5). On the poorest soils, jack pine forms pure stands. Slightly more productive soils carried mixtures of red and white pine. The best soils in the Pine
Barrens supported oaks. The forests in the northwestern Pine Barrens are dominated by red pine, despite the poor soils. The higher precipitation, lower summer temperature, and lower evapotranspiration due to the lake effect might have limited fire in this area. Furthermore, the rolling topography of the Bayfield Peninsula provided microhabitats where trees other than jack pine found favorable growing conditions.

Stand densities reveal a strong gradient, generally being lower in areas closer to the forest-prairie border region (Plate 2a). The recorded values in the southern Pine Barrens, which are often between 25 and 250 m, indicate landscapes of open forest and solitary trees. For comparison, in mesic hardwoods the average distance between corners and witness trees is about 11.6 m (K. Manies, unpublished data).
Plate 1. (a) Dominant tree species in the GLO data, (b) oak species distribution in the GLO data; (c) average diameter of oak in the GLO data.
Plate 2. (a) Average distance between witness trees and corners; (b) oak occurrence in the species level satellite image classification; (c) changes in the oak distribution from pre-settlement to today when examining the satellite image classification with a 21 pixel buffer (compare Figure 2).
Conclusions

Our GLO data analysis suggests that oak savannas were not widespread, but possibly existed as localized patches in the southern and southwestern Pine Barrens. In these regions, soil quality, stand densities, the presence of bur oak, and the relatively large tree diameters in the GLO data match the characteristics of oak savannas.

The increase of oak from pre-settlement times to today was detectable with different methods, and increases were particularly strong in areas where the GLO data contained oak as an understory species. This increase of oak is probably related to pine logging and fire suppression, which allowed oak sprouts to grow until they became part of the canopy.

What are the implications of our results for ecosystem management of the Pine Barrens? First, the Pine Barrens were not uniform in terms of oak occurrence. The surveyors mentioned red oak only in the northeastern Barrens. Pin oak was mostly recorded in the south-central Barrens and bur oak in the southwestern part of the Barrens. The poorest soils in the central Barrens probably did not contain much oak in pre-settlement times. This general distribution of oak species still occurs in the current landscape, but oak has increased overall.

The strong northeast-southwest density gradient at pre-settlement times (Plate 2a), when forests were more open in the southwest and denser in the northeast, diminished as forest came under management and fires were suppressed. Landscapes in the central part of the Pine Barrens were probably shaped by high intensity crown fires with return intervals of less than 50 years (Givnish 1995). Jack pine dominated this area as the fires and droughts prevented other species from dominating. If restoration of the pre-settlement conditions is attempted in this area, management should focus on large patches of open habitat that can resemble openings of fire origin. These open patches might shift in the landscape, and their features could be partially achieved by clear-cutting (Niemuth 1995). Upon the creation of a new, large open patch, a previous patch could be regenerated with jack pine. This management could mimic typical jack pine regeneration after fire for some habitat purposes. However, all processes typical of the fire-controlled landscape would not be duplicated with only logging. Areas of low tree density and substantial open areas (mean tree-corner distance of 0.25 – 2 km) also occurred within the jack pine-dominated central Barrens, on the poorest soils.

The northern Barrens in Bayfield County contained more diverse forests with a species mix of jack pine, red pine, white pine, and red oak. These mixed forests were relatively dense. The ecosystem in this area would probably benefit from forest management that maintains all species in the landscape. Large-scale disturbances were much less common in this area, but smaller, intense disturbance patches can be assumed due to the complete lack of trees at some corners.

In the southern and the southwestern Barrens, extensive crown fires were probably rare due to a higher density of lakes that functioned as fire breaks. In this region, red pine, white pine, and oak were interspersed with jack pine, but fires with lower intensity, although perhaps higher frequency, allowed oaks to reach diameters of 50 cm and more. The average distance between witness trees and the surveyed corner was often more than 50 m. This is the region where we assume local oak savannas occurred. Given that fire is a stochastic process, locations of oak savanna were not stationary. One area
with repeated low intensity fires might have become a savanna. Another area, after no fires for several decades, might have experienced a crown fire exposing mineral soil and creating conditions favorable to dense jack pine regeneration.

Ecosystem management and landscape restoration needs to take such natural variation into account, aiming for a constantly changing and heterogeneous mosaic at broad scales. Ideally, conservation efforts and restoration attempts should not focus on single sites but rather on the landscape as a whole, permitting all stages of natural vegetation types to exist. Such efforts need to be coordinated among landowners to be feasible at large scales, which can be difficult. However, it offers a chance to manage forests and to generate revenues while preserving ecosystem characteristics and varied habitat values. For example, during the harvest of a jack pine stand with an oak component, a resource manager may leave sparse cover of oaks and use prescribed burning in subsequent years to prevent jack pine regeneration. This stand could be maintained as an oak savanna for a few decades before the oak is removed and jack pine is seeded again. Such a savanna would not be identical to a pre-settlement savanna; its origin does not resemble a natural process. However, such management alternative may provide habitat as well as revenues in areas where large-scale prescribed burns are difficult.

We do not understand the Pine Barrens ecosystem enough to explain fully the influence of species composition and structure on long-term sustainability. However, our analysis helps us to know the general structure and species composition of the Pine Barrens at pre-settlement times even without a full understanding of the ecosystem’s complexity. These conditions were the result of an evolution of the Pine Barrens over thousands of years. When we think about the future of the Pine Barrens, the past can contribute useful guidelines.

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Volker C. Radeloff is a research assistant in the Department of Forest Ecology and Management, University of Wisconsin-Madison. His current research focuses on fire and jack pine budworm disturbance in the Pine Barrens landscape at pre-settlement times and today. Address: Dept. of Forest Ecology and Management, UW-Madison, 120 Russell Laboratories, 1630 Linden Drive, Madison, WI 53706-1598.

David J. Mladenoff is an associate professor in the Department of Forest Ecology and Management at the University of Wisconsin-Madison. His interests and research are particularly in the area of landscape ecology and northern forests. Address: Dept. of Forest Ecology and Management, UW-Madison, 120 Russell Laboratories, 1630 Linden Drive, Madison, WI 53706-1598.

Kristen L. Manies quantified surveyor bias in the General Land Office data in her master's project and derived methods to create landscape-scale vegetation maps from these data. She is currently at the U.S. Geological Survey in California.

Mark S. Boyce is the Vallier Chair of Ecology and Wisconsin Distinguished Professor in the College of Natural Resources at the University of Wisconsin-Stevens Point, and currently serves as Vice President of Sciences for the Wisconsin Academy of Sciences, Arts and Letters. Address: College of Natural Resources, UW-Stevens Point, Stevens Point, WI 54481.
Plate 1. A reconstructed depiction of a landscape scene in the oak savanna-woodland ecotone prior to development by European settlers (courtesy of The Nature Conservancy).