A Historical Perspective and Future Outlook on Landscape Scale Restoration in the Northwest Wisconsin Pine Barrens

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Abstract

The concurrent discussions of landscape scale restoration among restoration ecologists, and of historic disturbance pattern as a guideline for forest management among forest scientists, offer a unique opportunity for collaboration between these traditionally separated fields. The objective of this study was to review the environmental history, early restoration projects, and current plans to restore landscape patterns at broader scales in the 450,000 ha northwest Wisconsin Pine Barrens. The Pine Barrens offer an example of a landscape shaped by fire in the past. In northwestern Wisconsin historically the barrens were a mosaic of open prairie, savanna, and pine forests on very poor, sandy soils. The surrounding region of better soils was otherwise heavily forested. Six restoration sites have been managed since the middle of this century using prescribed burns to maintain the open, barrens habitat. However, these sites are not extensive enough to mimic the shifting mosaic of large open patches previously created by fire. Extensive clear-cuts may be used as a substitute for these large fire patches so that presettlement landscape patterns are more closely approximated in the current landscape. We suggest that such silvicultural treatments can be suitable to restore certain aspects of presettlement landscapes, such as landscape pattern and open habitat for species such as grassland birds. We are aware that the effects of fire and clear-cuts differ in many aspects and additional management tools, such as prescribed burning after harvesting, may assist in further approximating the effect of natural disturbance. However, the restoration of landscape pattern using clear-cuts may provide an important context for smaller isolated restoration sites even without the subsequent application of fire, in this formerly more open landscape.

Key words: disturbance, fire, forest management, landscape ecology, pine barrens, pattern, savanna, scale.

Introduction

Restoration ecology has traditionally focused on relatively small sites, but recently, restoring entire landscapes at much broader scales is being discussed (Naveh 1994; Zedler 1996; Kentula 1997). Landscape restoration of settled areas will require integrating conservation and productive use (Hobbs & Norton 1996). Such integration may not restore an assumed "natural" state of a landscape (White & Walker 1997). However, it may provide an important matrix for smaller restoration sites and preserves (Lamb 1998). Vital landscape attributes (VLAs) have been proposed for evaluating ecological restoration undertaken within a landscape perspective. Two important VLAs are (1) the type, number, and size range of land units, and (2) spread of disturbance across a landscape (Aronson & Le Floc'h 1996). Land unit patterns in relatively natural systems are often the result of disturbances such as fire, and an open question is how these VLAs can be restored in managed landscapes.

Concurrent with the discussion on landscape restoration, forest ecologists and managers are discussing using historic natural disturbance patterns as a guideline for forest ecosystem management (Attiwill 1994; Fulé et al. 1997). For example, natural stand structures in forests regenerated by gap dynamics may be best approximated when harvest is done using selection or shelterwood systems (Fries et al. 1997). Crown-fire dominated systems, however, may be more resilient against disturbance caused by clear cutting (Fries et al. 1997) if other conditions are met. The mean and the range of fire patch sizes can be a useful guideline for harvest unit sizes (Hunter 1993; Bondrupnielsen 1995). Such forest management may suitably restore elements of landscapes while still allowing commodity production (Lamb 1998).

Major changes occurred in North American forests with the advent of European settlement; many species

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were endangered, forest structure was changed, and ecosystem processes were altered (Williams 1989; Ehrlich 1996). Forests changed not only within sites in terms of their species composition, but also on broader scales in terms of their landscape pattern (Mladenoff et al. 1993; White & Mladenoff 1994). Disturbance processes such as windthrow and fire often shaped the landscape patterns of these early forests (Romme 1982; Canham & Loucks 1984; Turner 1989). Fire suppression altered landscape patterns in managed forests (Baker 1992; Fulé & Covington 1998), and current younger second-growth forests are less susceptible to windthrow. Reinstating the natural fire regimes to restore landscape structure may be possible in certain cases, such as extensive wilderness areas (Baker 1994), but is not socially acceptable in settled regions. For such areas, forest management that embraces natural disturbance pattern as a guideline may provide an important alternative for partially restoring landscape pattern, a vital attribute of many landscapes, due to the effects of pattern on ecological processes (Turner 1989).

Discussions on both landscape-scale restoration and on disturbance pattern as a guideline for forest management are ongoing and relatively new. There is a clear need for examples where these principles have been implemented. The Northwest Wisconsin Pine Barrens are an example for a landscape that was fire-dominated and characterized by a mosaic of openings, savannas, and forested patches on very sandy soils. The open Pine Barrens ecosystem was unique in northern Wisconsin, which was otherwise heavily forested. This region also has an interesting restoration history, starting in the 1940s at single sites, and currently expanding in scope to assess and restore the larger patterns of the presettlement landscape. The decline of game species characteristic of open habitat such as *Tympanuchus phasianellus* (sharp-tailed grouse) was the initial motivation for the designation of wildlife reserves (Hamerstrom et al. 1952) which are still actively managed with prescribed fire. However, these reserves are too small to permit restoring the shifting mosaic of openings created previously by wildfires. More recently, forest managers and conservationists began to consider how to manage the entire Pine Barrens region as an ecosystem. For example, it is proposed to aggregate clear-cuts in order to reintroduce large openings into the landscape (Borgerding et al. 1995; Parker 1996).

The objective of this study was to examine presettlement landscape pattern, restoration history, and possibilities for landscape scale restoration of a managed landscape to provide an example of how landscape restoration and forest management may combine forces. First, this article describes the Pine Barrens ecosystem to provide an understanding of the species, ecological processes, and landscape patterns of this region. Second, the environmental history of the area is briefly outlined. Third, the histories of four major restoration sites across the Pine Barrens region are compared. Finally, recent initiatives for Pine Barrens management at the landscape scale are described and suggestions are given for the future of the Pine Barrens as a landscape where humans and nature can coexist.

The Pine Barrens Ecosystem

Pine barrens ecosystems, which are not limited to Wisconsin, were never common and are decreasing throughout their former range (Forman 1979), thus raising conservation concerns (Good & Good 1984). The northwest Wisconsin Pine Barrens (hereafter referred to as Pine Barrens) are located on a sandy outwash plain with nutrient poor, sandy soils (Fig. 1). The ecology and the environmental history of the Pine Barrens is described in detail elsewhere (Murphy 1931; Radeloff et al. 1998, 1999); however, a brief introduction will be given here.

Environmental History of the Pine Barrens

Like most areas of Wisconsin, the area of the Pine Barrens was covered by ice during the last glaciation. Both climate and vegetation have varied since glaciation. The Pine Barrens region is part of the border region between western prairies and eastern forest. After the most recent glaciation, the prairies expanded eastward

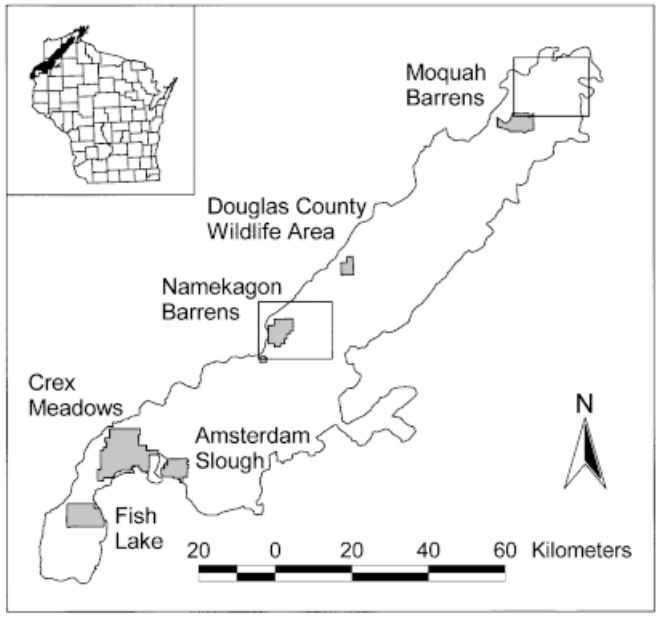

Figure 1. Location of the Northwest Wisconsin Pine Barrens and current restoration sites in the area shown in grey. The two boxes refer to areas shown in detail in Fig. 2a and 2b.

and reached their maximum eastward point at 7000 BP. Since then a cooling trend has permitted the westward expansion of forests (Davis 1993). The balance between forested and open patches has changed as has the tree composition, and it is important to note there was not just one "natural" state since the last glaciation (Wilson 1938; Wright 1968; Craig 1972). Furthermore, crown fires may have been so extensive that the landscape did not converge to equilibrium but experienced a range of variability (Baker 1989; Sprugel 1991; White & Walker 1997).

Historical Records of the Presettlement Vegetation

Determining how the vegetation of the Pine Barrens looked before European settlers arrived in the second half of the nineteenth century is challenging, and even less is known about temporal variation of the landscape. At that time, Ojibwa (Chippewa) lived in the Pine Barrens region. During the seventeenth and eighteenth centuries they drove the Dakota (Sioux) from most of the area, although conflicts with these people continued into the nineteenth century. The Ojibwa may have burned forests to improve hunting and the blueberry crop, but their total impact on the landscape is difficult to estimate (Murphy 1931).

Explorers, traders, and trappers have frequently traversed the area since the seventeenth century, but only sparse accounts of the vegetation exist for this time period. In their diaries these early explorers described the rivers and lakes they traveled by canoe rather than the vegetation they saw (Curtis 1959; Vogl 1964). The earliest data beyond anecdotal evidence were collected when the U.S. General Land Office (GLO) carried out the public land survey of Wisconsin. About every 800 m (0.5 miles) surveyors placed a corner post and marked two to four trees, recording tree species, diameter, distance, and bearing from the post, and thus indirectly stand density. A number of studies have used GLO records for parts of the Pine Barrens (Fassett 1944; Thomson & Fassett 1945; Vogl 1964). An ongoing project at the University of Wisconsin is expanding these studies by entering all data in a geographical information system (GIS) database (Manies 1997). This work has been completed for the Pine Barrens, and the resulting maps provide a detailed spatial account of the Pine Barrens vegetation at the advent of European settlement (Radeloff et al. 1998, 1999).

The sandy, drought-prone soils created conditions favorable for recurrent forest fires before the advent of European settlement. Fire disturbance was frequent, but return intervals and intensities varied throughout the region (Curtis 1959; Vogl 1970; Radeloff et al. 1998). In the southern part, frequent, low-intensity ground fires were common, creating savannas dominated by *Pinus resinosa* (red pine), *Quercus ellipsoidalis* (pin oak), and *Q. macrocarpa* (bur oak) (Radeloff et al. 1998). These species are adapted to ground fires; red pine and bur oak have relatively thick bark, and pin oak resprouts vigorously when the canopy is killed.

The central part of the Pine Barrens was almost entirely dominated by *Pinus banksiana* (jack pine) in variable densities. Jack pine is adapted to crown fires due to its serotinous cones that remain closed in the crown until a fire melts the resin bond and seeds are released. Favorable seed bed conditions after a fire often lead to very dense, "dog-haired" regeneration. This allows jack pine to out-compete later successional species such as red pine and oaks, as long as extensive crown fires reoccur (Heinselman 1973, 1981).

The northern part of the Pine Barrens contained mixed pine forests where red pine, jack pine, and *Pinus strobus* (white pine) were common. Forests were relatively dense and fire probably less common.

Logging, Farming, and Reforesting—Developments Since 1860

European settlement had a profound impact on the Pine Barrens. In the *Geology of Wisconsin,* Strong (1877) is the first to mention vegetation changes due to white settlers: "On some of these 'prairies' however, young trees are springing up ... These have been appealed to as examples of prairie returning to forest, since annual fires are no longer permitted to ravage the region." The described lack of fire may have been caused by a series of rainy years, rather than by fire suppression (Vogl 1964), but this statement gives early evidence that since the second half of the nineteenth century, white settlers had become the dominant factor of landscape change.

The surveys of the GLO laid the groundwork for exploitation of the Pine Barrens, and intensive logging of red and white pine started in the mixed pine forests of the northern Pine Barrens and in the red pine savannas of the southern Pine Barrens about 1860 (Murphy 1931). After an area was harvested, the increased fuel load led to fires induced by railroad locomotives or from logging camps. These fires were not seen as a threat but rather as an aid to farmers in clearing the land. Following the loggers, farmers settled the Pine Barrens, despite the low fertility of the soils. The openness of the Pine Barrens made homesteading easy and the thin sandy soils were easily plowed. After 1910, another wave of logging started, as a response to the use of jack pine pulp wood in paper mills, and in 1931 Murphy wrote, "The quantity of jack pine of pulpwood size which still remains in the Barrens is not great" (Murphy 1931). The sudden lack of timber induced initiation of a fire suppression system in the 1920s. The efficiency of forest protection in those early years, however, should not be overestimated; in 1931 alone, more

than 30,000 ha burned throughout the Pine Barrens (Vogl 1964).

By 1930 there were few trees left, the soils of the agricultural areas were depleted, and other industries (e.g., tourism and fur farms) were rare. Extreme droughts in northwestern Wisconsin and the financial depression of the entire United States increased the crisis, so that settlers in the Pine Barrens could no longer meet their tax obligations. They abandoned their lands and ownership reverted to the counties, and county forests, national forests, or private industrial forest holdings were established. Natural regeneration and workers of the Civilian Conservation Corps re-established vast areas with jack pine on these units as well as on private lands (Woerpel 1963; Vogl 1964).

Reforestation and fire suppression were the major forces for landscape change since the 1930s. The result was a strong decrease of open habitat. At presettlement times, fire was not only important for jack pine regeneration, it also shaped the landscape structure and created large open patches where crown fires occurred, and savannas and prairies where ground fires were frequent. Such open patches are an essential habitat feature for animals and plant species typical of the Pine Barrens (Vogl 1964; Mossman et al. 1991). The sharp-tailed grouse is a bird that requires vast open patches. A recent population viability analysis estimated the minimum area of open habitat necessary to support an isolated sharp-tailed grouse population to be 4,000 ha (Temple 1992). Open patch sizes and grassland bird diversity have a strong positive correlation. In a recent survey, some species like *Passerculus sandwichensis* (savannah sparrow) and *Dolichonyx oryzivorus* (bobolink) were only found in open patches ⩾2,000 ha in size (Niemuth 1995).

Early Restoration Projects

The period of change in the 1930s and 1940s was also a time when the first pine barrens restoration projects started. Motivation to restore Pine Barrens habitat was twofold. Early habitat management experiments using prescribed burning had been conducted in southern Wisconsin by forward thinkers such as Herbert L. Stoddard, Wallace B. Grange, and Aldo Leopold. At the University of Wisconsin Arboretum, they tried to restore prairies and savannas for species that depended on such habitat. Their early failures to restore prairie without prescribed burning made it obvious that certain habitats required active management (Vogl 1967). The example set by these early restoration experiments suggested the use of prescribed burning in the Pine Barrens. The second motivation was the decrease of sharp-tailed grouse, caused by the decrease of open habitat, which concerned wildlife managers in the Pine Barrens region (Hamerstrom et al. 1952; Doll 1953). These concerns led to the establishment of six major restoration sites in the Pine Barrens, the five southern ones managed by the Wisconsin Department of Natural Resources (DNR) and the Moquah Barrens in the North by the Chequamegon National Forest (Fig. 1). All these restoration areas are actively managed as open brush prairie. The dominant treatment is prescribed burning in 5–10 year rotations supplemented by tilling, mowing, and the application of herbicides where oak cover becomes too dense (Table 1).

Table 1. Comparison of the treatments of restoration sites in the Pine Barrens (modified after Borgerding et al. 1995)

		Barrens Habitat (in ha)		*Applied Treatments*			
	Year of Origin	*Current*	*Goal*	*Burning*	*Tilling*	*Mowing*	*Spraying*
Crex Meadows Wildlife Area	1948	7,065	7,270	x	x	x	x
Fish Lake Wildlife Area	1960	970	1,615	x			
Amsterdam Slough Wildlife Area	1968	240	810	x			
Kohler-Peet Barrens	1978	260	365	x			
Namekagon Barrens Wildlife Area	1956	1,900	3,755	x			
Douglas County Wildlife Area	1948	1,455	1,615	x	x	x	x
Moquah Barrens Wildlife Management Area	1953	1,735	2,420	x	x	x	
Total		13,910	17,845				

Crex Meadows

In 1945, the Wisconsin Conservation Department bought 4,800 ha from Burnett County, paying $7.51 per hectare (Vogl 1964). Currently, Crex Meadows (12,180 ha), together with the Fish Lake Wildlife Area (5,715 ha) and the Amsterdam Slough Wildlife Area (2,927 ha), form the Glacial Lake Grantsburg Wildlife Management Complex. All of these sites have a mixture of upland and lowland habitat. This means that only parts of the areas are suitable for barrens restoration, whereas others were covered by wetlands and marshes during presettlement times.

In 1948, soon after the establishment of Crex Meadows as a wildlife area, game manager Norman Stone was permitted to use prescribed burning in order to maintain open habitat and to reduce woody cover. Since then, the management goal has been to burn upland sites every 5–10 years and "as a result, Crex Meadows has become a showplace for fire and its uses, and is the most intensively burned wildlife area in the state" (Vogl 1967).

Douglas County Wildlife Area

The Douglas County Wildlife Area (DCWA) had been a part of the bird dog field-trial circuit since 1925 and was established as an official site in 1948. Here the first prescribed burn in northwestern Wisconsin was conducted by James B. Hale in 1947 (Vogl 1967). Today, DCWA provides 1,365 ha of open habitat. At DCWA, wildlife managers aim to keep solitary trees and groups of pines to approximate an envisioned savanna landscape. One technique is to prune lower branches of red pine before prescribed burns so that fire cannot jump into the crowns.

Namekagon Barrens

In the Namekagon Barrens, controlled burns have been conducted since 1958, and wildfires occurred in 1929, 1931, 1947, and 1958, i.e., there has never been a period in the history of the Namekagon Barrens without fire (Vogl 1970). A recent count of the sharp-tailed grouse population found 55 males on dancing grounds, which is the highest population since the earliest survey in 1950. Besides open habitat on 1,900 hectares, the Namekagon Barrens provide an important stepping stone between the three major restoration sites around Grantsburg and the DCWA farther north.

Moquah Barrens

Located within Chequamegon National Forest, the Moquah Wildlife Area was designated in 1953 to provide open habitat for sharp-tailed grouse. Recently, there was concern that the intense burn pattern did not recreate presettlement vegetation and some argued for a higher variety in the overall pattern. In 1991, approximately 280 ha adjacent to the 1860 ha of the Moquah Wildlife Area were designated as the Moquah Barrens Restoration Site (Vora 1993). Here the burning is less intense; small forested patches and single large trees are left in varying quantities creating a savanna-type landscape.

Discussion

Problems with the Current Restoration Approach

The current management sites have been successful in terms of maintaining large patches of open habitat. For example, the size of the Namekagon Barrens is in the same order of magnitude as the biggest recent fire in the Pine Barrens (Fig. 2a). However, these restoration sites only partly resemble presettlement conditions. The presettlement landscape structure of the central portion of the Pine Barrens was dynamic; fires created a shifting mosaic where large openings were frequent but not fixed in space. This shifting mosaic cannot be restored within the current restoration sites, because of their limited size. Frequent prescribed burning keeps the restoration sites open, but these fires are not as intense as crown fires in mature jack pine stands (Johnson & Miyanishi 1995), and prescribed burns do not contain equivalent amounts of coarse woody debris and snags (Niemuth & Boyce 1998).

Plans to Restore Landscape Patterns with Forest Management

Attempts to approximate the shifting mosaic of the central Pine Barrens more fully using forest management are currently being explored in both the Douglas County Forest, and in the Chequamegon National Forest. Previously, the size of cutting units was limited to 40 acres, creating a landscape structure very different from the presettlement conditions (Fig. 2b). Noting this discrepancy, ecologists and foresters now discuss clear cuts of 200–400 ha in this formerly open landscape, followed by natural revegetation rather than plantations (Parker 1996). The lack of topography in the Pine Barrens and the small number of streams limit the danger of causing erosion by clear-cutting, which is an important consideration in other forested ecosystems.

In Douglas County the goal is to have 20% of the 14,570 ha of county forest "open" at any given point in time and to allocate these openings in two to three large patches. These patches are maintained as barrens until other barrens have been established by clear-cutting. At that point the old barrens will be reforested (F. Strand, Wisconsin DNR, personal communication). The hope is that such a dynamic habitat concept may be suitable to maintain all successional stages, and to provide habitat for barrens species while still utilizing forests for timber management.

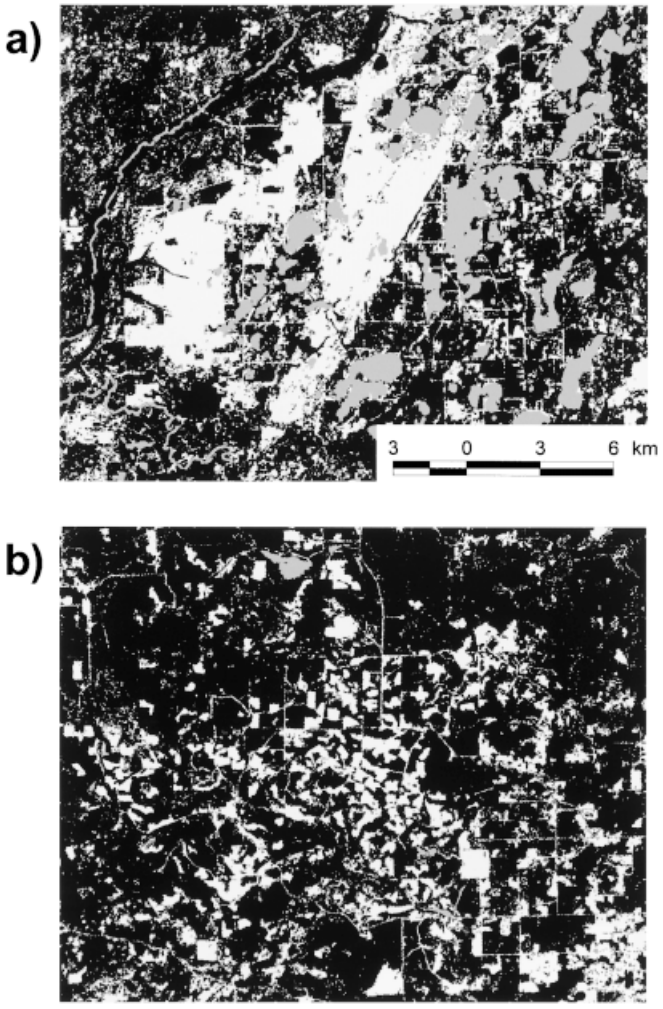

Figure 2. Satellite classification showing forests in black, water bodies in gray and grasslands/brush in white; (a) a triangular patch of the "5-mile fire" and the open Namekagon Barrens, a wildlife management area kept open using prescribed burning, to the West of the fire patch (the area depicted in this image is located in the central Pine Barrens, compare box on Fig. 1), and (b) small clear-cuts (white areas) that are highly dispersed (the area depicted in this image is located in the northern Pine Barrens, compare box on Fig. 1). Data courtesy of Wolter et al. 1995.

In Bayfield County, foresters and wildlife managers keep extensive areas open that function as both firebreaks and sharp-tailed grouse habitat. Two 8×0.4 km breaks form a core of 700 ha; forest cuts adjacent to these breaks will provide a further 500 ha of transient open habitat (F. Strand, Wisconsin DNR, personal communication).

Implementing and Evaluating Landscape Pattern Restoration in the Pine Barrens

Landscape pattern restoration across a region the size of the Pine Barrens will require coordinated management among multiple landowners. Land ownership in the Pine Barrens varies. The northern Pine Barrens are part of the Chequamegon National Forest. The central Pine Barrens contain extensive areas owned by private industrial forest holdings, and by Douglas and Bayfield County forests. The southern Pine Barrens contain predominantly holdings of small private landowners, but also extensive areas owned by Burnett and Washburn County forests, and by the State of Wisconsin. This pattern of land ownership potentially permits landscape pattern restoration, especially in the central and northern Pine Barrens, by agreement of relatively few landowners.

Such a potential future agreement was facilitated by two meetings organized by the Wisconsin DNR in 1993 and 1999 that discussed the future of the northwest Wisconsin Pine Barrens (Borgerding et al. 1995). Representatives of all major landowners, managing agencies, scientists, and interested public attended these meetings. Furthermore, the Wisconsin DNR is currently developing an adaptive management project for the Pine Barrens with the support of the U.S. Environmental Protection Agency (G. Bartelt, Wisconsin DNR, personal communication). The goal of this project is to reach a consensus among the different interest groups, managers, and scientists about the future management of the Pine Barrens. The goal is also to complement the proposed management changes with a monitoring program that can identify ecosystem changes in response to management. The results of this monitoring program may then be used to adapt ecosystem management practices. However, it is important to note that it is not the goal to restore the entire Pine Barrens area to presettlement conditions, but rather to adapt management so that conservation objectives can be met simultaneously with commodity production.

Clear-Cuts Versus Fires

Clear-cuts may be suitable for mimicking the size and shape of fire-generated openings, but it is important to note that other fire effects are not approximated. Fire-generated openings exhibit a high degree of spatial heterogeneity (Turner et al. 1997), that may differ from clear-cuts. Studies comparing jack pine stands after fires and clear-cuts found similar bird communities (Greenberg et al. 1995; Niemuth 1995), but significant differences in carabid assemblages (Beaudry et al. 1997), herbaceous species (Whittle et al. 1997), and microbial diversity (Staddon et al. 1998). Differences in fire frequency affect jack pine serotiny (Gauthier et al. 1996), and the abundance of coarse woody debris (Niemuth & Boyce 1998). Clear-cuts are often regenerated artificially using furrows to provide a suitable seed bed for tree planting (personal observation). These furrows may disrupt soil systems and understory vegetation. Natural re-

generation, and potentially prescribed burning after harvesting (Chrosciewicz 1988), may be an ecologically suitable way of re-establishing jack pine, thus restoring another portion of the original ecological processes.

Conclusions

Active restoration using prescribed burning has a long tradition in the Pine Barrens and management for open-habitat game species such as sharp-tailed grouse has been successful. However, in order to restore more elements of the native Pine Barrens landscape, conservationists and managers will have to answer the question of how managed forests beyond the established restoration sites can contribute to landscape-scale restoration efforts. Isolated barrens patches in a vast sea of even-aged plantations cannot ensure that this ecosystem will be perpetuated for coming generations. Yet landscape-scale management of the Pine Barrens forest may create habitat and a fuller range of ecosystems without taking forest out of production. In this context, the new initiatives of forest managers to aggregate clear-cuts so that presettlement landscape patterns are more closely resembled have interesting potential.

The discussions and management experiments of the Pine Barrens are an example for the restoration of other disturbance-prone ecosystems. The concurrent discussions about the restoration of landscape patterns, and the use of disturbance patterns as management guidelines can build a bridge between the traditionally separated fields of restoration ecology, landscape ecology, and forest management (Attiwill 1994; Bell et al. 1997). The restoration of many settled landscapes may only be feasible if cultural and ecological aspects are integrated (Naveh 1998). Such restoration may be limited to certain aspects of an ecosystem, such as the landscape structure (Lamb 1998), but this can be an important matrix for smaller restoration sites where more intense management is feasible.

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LITERATURE CITED

Aronson, J., and E. Le Floc'h. 1996. Vital landscape attributes: missing tools for restoration ecology. Restoration Ecology **4:** 377–387.

Attiwill, P. M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. Forest Ecology and Management **63:**247–300.

Baker, W. L. 1989. Landscape ecology and nature reserve design in the Boundary Waters Canoe Area, Minnesota. Ecology **70:** 23–35.

Baker, W. L. 1992. Effects of settlement and fire suppression on landscape structure. Ecology **73:**1879–1887.

Baker, W. L. 1994. Restoration of landscape structure altered by fire suppression. Conservation Biology **8:**763–769.

Beaudry, S., L. C. Duchesne, and B. Côté. 1997. Short-term effects of three forestry practices on carabid assemblages in a jack pine forest. Canadian Journal of Forest Research **27:**2065–2071.

Bell, S. S., M. S. Fonseca, and L. B. Motten. 1997. Linking restoration and landscape ecology. Restoration Ecology **5:**318–323.

Bondrupnielsen, S. 1995. Forestry and the boreal forest—maintaining inherent landscape patterns. Water, Air and Soil Pollution **82:**71–76.

Borgerding, E. A., G. A. Bartelt, and W. M. Cowen, editors. 1995. The future of pine barrens in northwest Wisconsin: a workshop summary. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Canham, C. D., and O. L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology **65:**803–809.

Chrosciewicz, Z. 1988. Jack pine regeneration following postcut burning under seed trees in central Saskatchewan. Forestry Chronicle **64:**315–319.

Craig, A. J. 1972. Pollen influx to laminated sediments: a pollen diagram from northeastern Minnesota. Ecology **53:**46–57.

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, Wisconsin.

Davis, M. B. 1993. Holocene vegetational history of the eastern United States. Pages 166–181 in H. E. Wright, editor. Late-quaternary environments of the United States. University of Minnesota Press, Minneapolis, Minnesota.

Doll, A. D. 1953. Sharptails on the Chequamegon. Wisconsin Conservation Bulletin **18:**17–19.

Ehrlich, P. R. 1996. Conservation in temperate forests: What do we need to know and do? Forest Ecology and Management **85:**9–19.

Fassett, N. C. 1944. Vegetation of the Brule basin, past and present. Transactions of the Wisconsin Academy of Science, Arts and Letters **36:**33–56.

Forman, R. T. T. 1979. Pine barrens: ecosystem and landscape. Academic Press, New York.

Fries, C., O. Johannsson, and B. Pettersson. 1997. Silvicultural models to maintain and restore natural stand structures in Swedish boreal forests. Forest Ecology and Management **94:** 89–103.

Fulé, P. Z., and W. W. Covington. 1998. Spatial patterns of Mexican pine-oak forests under different recent fire regimes. Plant Ecology **134:**197–209.

Fulé, P. Z., W. W. Covington, and M. M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications **7:**895–908.

Gauthier, S., Y. Bergeron, and J.-P. Simon. 1996. Effects of fire regime on the serotiny level of jack pine. Journal of Ecology **84:** 539–548.

Good, R. E., and N. F. Good. 1984. The Pinelands National Reserve: an ecosystem approach to management. BioScience **34:** 169–173.

Greenberg, C. H., L. D. Harris, and D. G. Neary. 1995. A comparison of bird communities in burned and salvaged-logged, clear-cut, and forested Florida sand pine scrub. Wilson Bulletin **107:**40–54.

Hamerstrom, F., F. Hamerstrom, and D. E. Matson. 1952. Sharptails into the shadows. Wisconsin Conservation Department, Madison, Wisconsin.

Heinselman, M. L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research **3:** 329–382.

Heinselman, M. L. 1981. Fire and fire succession in the conifer forests of northern North America. Pages 372–405 in D. C. West, H. H. Shugart, and D. B. Botkin, editors. Forest succession—concepts and application. Springer Verlag, New York.

Hobbs, R. J., and D. A. Norton. 1996. Towards a conceptual framework for restoration ecology. Restoration Ecology **4:** 93–110.

Hunter, M. L. 1993. Natural fire regimes as spatial models for managing boreal forests. Biological Conservation **65:** 115–120.

Johnson, E. A., and K. Miyanishi. 1995. The need for consideration of fire behavior and effects in prescribed burning. Restoration Ecology **3:**271–278.

Kentula, M. E. 1997. A step toward a landscape approach in riparian restoration. Restoration Ecology **5:**2–3.

Lamb, D. 1998. Large-scale ecological restoration of degraded tropical forest lands: the potential role of timber plantations. Restoration Ecology **6:**271–279.

Manies, K. L. 1997. Evaluation of General Land Office survey records for analysis of the northern Great Lakes hemlock-hardwood forests. M.S. Thesis. University of Wisconsin–Madison, Madison, Wisconsin.

Mladenoff, D. J., M. A. White, J. Pastor, and T. R. Crow. 1993. Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes. Ecological Applications **3:**294–306.

Mossman, M. J., E. Epstein, and R. M. Hoffmann. 1991. Birds of Wisconsin pine and oak barrens. Passenger Pigeon **53:**137–163.

Murphy, R. E. 1931. Geography of northwestern pine barrens of Wisconsin. Transactions of the Wisconsin Academy of Sciences, Arts and Letters **26:**96–120.

Naveh, Z. 1994. From biodiversity to ecodiversity: a landscape ecological approach to conservation and restoration. Restoration Ecology **2:**180–189.

Naveh, Z. 1998. Ecological and cultural landscape restoration and the cultural evolution towards a post-industrial symbiosis between human society and nature. Restoration Ecology **6:** 135–143.

Niemuth, N. D. 1995. Avian ecology in Wisconsin pine barrens. Ph.D. Dissertation. University of Wyoming, Laramie, Wyoming.

Niemuth, N. D., and M. S. Boyce 1998. Disturbance in Wisconsin Pine Barrens: implications for management. Transactions of the Wisconsin Academy of Sciences, Arts and Letters **86:** 167–176.

Parker, L. 1996. Restaging an evolutionary drama: thinking big on the Chequamegon and Nicolet National Forests. Pages 218–219 in K. A. Kohm, and J. F. Franklin, editors. Creating a forestry for the 21st century: the science of ecosystem management. Island Press, Washington, D.C.

Radeloff, V. C., D. J. Mladenoff, K. L. Manies, and M. S. Boyce. 1998. Analyzing landscape restoration potential: pre-settlement and current distribution of oaks in the northwest Wisconsin Pine Barrens. Transactions of the Wisconsin Academy of Sciences, Arts and Letters **86:**189–205.

Radeloff, V. C., D. J. Mladenoff, H. S. He, and M. S. Boyce. 1999. Forest landscape change: the northwest Wisconsin Pine Barrens before European settlement and today. Canadian Journal of Forest Research **29:**1649–1659.

Romme, W. H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. Ecological Monographs **52:**199–211.

Sprugel, D. G. 1991. Disturbance, equilibrium, and environmental variability: what is 'natural' vegetation in a changing environment? Biological Conservation **58:**1–18.

Staddon, W. J., L. C. Duchesne, and J. T. Trevors. 1998. Impact of clear-cutting and prescribed burning on microbial diversity and community structure in a jack pine (*Pinus banksiana* Lamb.) clear-cut using Biolog Gram-negative microplates. World Journal of Microbiology and Biotechnology **14:** 119–123.

Strong, M. 1877. The geology of the upper St. Croix district: soils and vegetation. Geology of Wisconsin **3:**375–381.

Temple, S. A. 1992. Population viability analysis of a sharp-tailed grouse metapopulation in Wisconsin. Pages 750–758 in D. R. McCullough, and R. H. Barrett, editors. Wildlife 2001: populations. Elsevier Applied Science, New York.

Thomson, J. W., and N. C. Fassett. 1945. The past and present vegetation of the Brule River watershed. Wisconsin Conservation Bulletin **10:**3–8.

Turner, M. G. 1989. Landscape ecology: the effect of pattern on process. Annual Review of Ecology and Systematics **20:** 171–197.

Turner, M. G., W. H. Romme, R. H. Gardner, and W. W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. Ecological Monographs **67:**411–433.

Vogl, R. J. 1964. Vegetational history of Crex Meadows, a prairie savanna in northwestern Wisconsin. American Midland Naturalist **72:**157–175.

Vogl, R. J. 1967. Controlled burning for wildlife in Wisconsin. Pages 47–96 in Proceedings of the 7th Tall Timbers Fire Ecology Conference. Hoberg, California. Tall Timbers Research Station, Tallahassee, Florida.

Vogl, R. J. 1970. Fire and the northern Wisconsin pine barrens. Pages 175–209 in Proceedings of the 10th Annual Tall Timbers Fire Ecology Conference. Fredericton, New Brunswick, Canada. Tall Timbers Research Station, Tallahassee, Florida.

Vora, R. S. 1993. Moquah Barrens: pine barrens restoration experiment initiated in Chequamegon National Forest. Restoration and Management Notes **11:**39–44.

White, M. A., and D. J. Mladenoff. 1994. Old-growth forest landscape transitions from pre-European settlement to present. Landscape Ecology **9:**191–205.

White, P. S., and J. L. Walker. 1997. Approximating nature's variation: selecting and using reference information in restoration ecology. Restoration Ecology **5:**338–349.

Whittle, C. A., L. C. Duchesne, and T. Needham. 1997. The impact of broadcast burning and fire severity on species composition and abundance of surface vegetation in a jack pine (*Pinus banksiana*) clear-cut. Forest Ecology and Management **94:** 141–148.

Williams, M. 1989. Americans and their forests: a historical geography. Cambridge University Press, New York.

Wilson, L. R. 1938. The postglacial history of vegetation in northwestern Wisconsin. Rhodora **40:**137–175.

Woerpel, L. S. 1963. Progress on the Chequamegon. Wisconsin Conservation Bulletin **28:**20–21.

Wolter, P. T., D. J. Mladenoff, G. E. Host, and T. R. Crow. 1995. Improved forest classification in the Northern Lake States using multi-temporal Landsat imagery. Photogrammetric Engineering and Remote Sensing **61:**1129–1143.

Wright, H. E. 1968. The roles of pine and spruce in the forest history of Minnesota and adjacent areas. Ecology **49:**937–955.

Zedler, J. B. 1996. Coastal mitigation in Southern California: the need for a regional restoration strategy. Ecological Applications **6:**83–94.