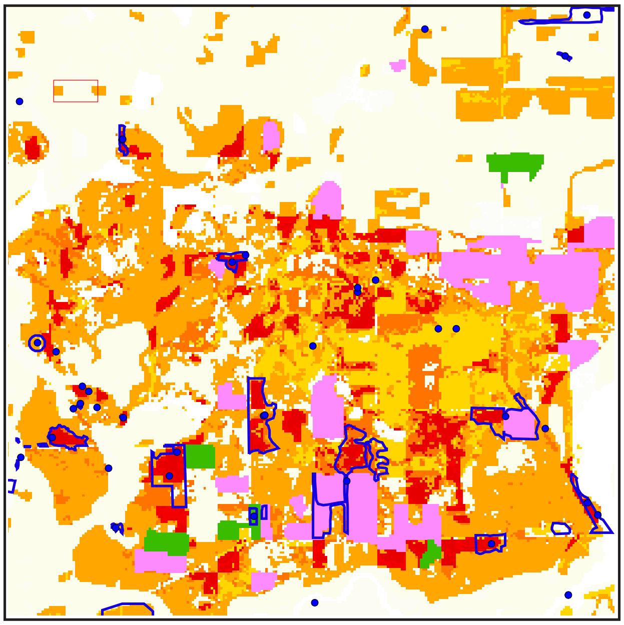
A GIS model for prairie and savanna restoration: Prioritizing areas at state, regional and local scales



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Cover image: Potential restoration areas in Brooks Township, Newaygo County based on GIS modeling.

Abstract

Prairies and savannas in the Midwest are highly imperiled along with much of their flora and fauna. Restoration of these ecosystems is an increasing focus among both public agencies and non-governmental organizations, but often efforts are focused on specific known sites without regard to unsurveyed areas and larger landscape-level connectivity necessary to support biodiversity over the long term. A GIS model to assess restoration potential was constructed by examining land use change from circa 1800 (based on GLO surveys) to 2000 (based on IFMAP) in 305 known high-quality sites occupying over 16,000 acres. Areas scoring higher in the model had land use change categories with a better likelihood of supporting remnant prairie and savanna communities. A second model was developed to guide intensive restoration of current and former agricultural areas and pine plantations in areas historically occupied by prairie and savanna vegetation. The model results were compared at different scales against more traditional approaches to prioritizing restoration, including maps of historical distribution of prairies and savannas, maps of known rare species occurrences, and aerial photographs. While the model was determined to have some utility, it also suffered from inaccuracies in both the circa 1800s data and IFMAP2000 data as well as problems with comparing data collected at vastly different spatial scales. Overall, the model can be carefully used as a potential but untested tool, deferring at the local scale to other, more well-established and accurate tools for restoration prioritization such as aerial photo interpretation and field surveys.

Introduction

<u>Background on restoration</u>

Prairies and savannas are among the most imperiled ecosystems in the Midwest. Once occupying tens of millions of acres, they have been reduced by over 99% due to conversion to agriculture, development, and succession to closed-canopy forest due to altered fire regimes (Nuzzo 1986, Curtis 1959). Numerous animals and plants require prairies and savannas for their primary habitat, and many of these species have experienced drastic declines due to the near complete loss of these ecosystems. Overall, prairies and savannas support a greater number of rare and declining species than any other single terrestrial habitat type in Michigan (Eagle et al. 2005).

For these reasons, restoration of prairies and savannas has increasingly become a priority for both government agencies and non-profit conservation organizations at the state, regional, and local levels. These include both restoration of natural remnants and the creation of grasslands by planting seed in former agricultural sites. In some cases, these restoring efforts have an immediate impact on resident plants and animals, and provide habitat for highly mobile species like grassland birds regardless of their location in relation to other habitats. However, the benefits to less mobile rare and declining species are much less clear. Additionally, many species, from Henslow's sparrows to box turtles, require large landscapes (a hundred acres or more) of contiguous habitat to support large, successful breeding populations. Thus, if restoration is to be ultimately successful in improving the habitat and viability of species, it must be concentrated and focused on large landscape areas.

<u>The Need for Landscape-level Prioritization</u>

Currently, restoration of remnants is often limited to the highest quality sites with the rarest species. While this approach is valid given limited resources, it lacks the larger landscape-level impact needed to benefit entire populations and leads to geographic isolation. In addition, projects are often limited to known areas of high-quality habitat while adjacent unsurveyed areas that may be equally important are ignored.

Grassland creation efforts are even more scattered in their approach and spatial distribution. Often, projects are largely opportunistic, based solely on the desire of the landowner and without regard to large-scale habitat benefits. Some government programs, such as the Conservation Reserve Enhancement Program (CREP), which encourages farmers to take land out of agricultural production and convert it to grassland habitat, recognize the landscape benefits of a more focused approach by limiting the scope of projects to certain regions. However, despite this semi-focused approach, these priority areas are still very large in size and still result in a shot-gun pattern of improved habitat that is of questionable value to the target species.

In addition, grasslands are often planted without regard to their historical distribution, juxtaposed with mature or recovering woodlots with a closed canopy forest. While these plantings may accomplish goals of reducing soil erosion and providing habitat to a limited number of species, focusing efforts on regions and sites with more suitable landscape context, such as a site surrounded by remnant savanna and open wetlands, are likely provide substantially more benefits to a much larger number of species.

Landscape-level modeling of potential restoration areas can benefit planners and land managers in several ways. By focusing projects on large sites and corridors in key regions, efforts are much more likely to accomplish ultimate goals of restoring functional populations of species. In addition, identifying target areas and sites in advance facilitates easier decision-making when restoration opportunities arise. Finally, prioritizing work on areas with the greatest potential to have a positive impact allows limited resources to be utilized more effectively.

Here we propose a GIS model to guide restoration and planning efforts, and compare it with other tools such as maps of presettlement vegetation, aerial photo interpretation, and field surveys.

Modeling Approach

Due to the differing nature of remnant restoration and grassland creation, two separate models were developed for each approach. For remnants, we utilized known high-quality areas and analyzed changes in land use patterns between circa 1800 and 2000. Known high-quality prairie and savanna sites were based on element occurrences (EOs) identified by 25 years of field surveys by ecologists with the Michigan Natural Features Inventory (MNFI) (Table 1). These areas, delineated in GIS by spatial polygons, were an ideal starting place from which to develop baseline data. Once land cover change was assessed in known high-quality areas, it was then applied to the entire landscape to delineate other potential areas for restoration.

Land use circa 1800, in 1978, and in 2000 were chosen as the primary predictive variables due to their statewide availability and ability to encompass a wide variety of important variables, such as historical distribution, current vegetation type, current successional stage, soil type, and disturbance history. All three data sources are widely available and though differing their origin and scale of accuracy, are generally accepted as the best information available.

Land use circa 1800 was determined by analyzing survey notes collected by the General Land Office (GLO) survey (1816-1856), in which surveyors established town, range, and section corners by walking section lines and recording witness and bearing trees (Comer et al. 1995). In addition to noted trees and written descriptions, vegetation delineation was enhanced by consulting soils and topographic maps, facilitating interpolation between section lines. It is generally accepted that this data is more suitable to assessment of large-scale vegetation patterns than being descriptive of land cover at any particular site, though surveyors often did make specific notes regarding prairies and savannas they crossed (Manies and Mladenoff 2000).

Table 1. High-quality prairie and savannas based on element occurrences identified by field surveys by the Michigan Natural Features Inventory.

Community Type	Number of Sites	Acres
Bur oak plains	0	0
Dry sand prairie	16	540
Hillside prairie	9	55
Lakeplain mesic prairie	1	77
Lakeplain oak openings	11	1550
Lakeplain wet prairie	15	613
Lakeplain wet-mesic prairie	29	714
Mesic prairie	3	13
Mesic sand prairie	8	154
Northern wet-mesic prairie	3	208
Oak barrens	11	653
Oak openings	1	3
Oak-pine barrens	23	4421
Pine barrens	13	2085
Prairie fen	133	4699
Wet prairie	8	165
Wet-mesic prairie	10	91
Woodland prairie	11	91
Grand Total	305	16132

Land use in 1978 and in 2000 were other primary data sources. Though somewhat redundant, these data have important differences in the way they were compiled in addition to representing slightly different time frames. Land use in 1978 was determined by expert aerial photo interpretation, allowing professional expertise to fine-tune subtle differences in vegetation. In contrast, land use in 2000 was determined by a combination of computer analysis of satellite images and ground-truthing. Though both data sets have inherent biases and weaknesses, utilizing both allowed us to capture the strengths of each. In general, land use in 2000 was used as the second variable in the land use change analysis (1800 to 2000) and land use in 1978 was used as a filter to increase the score of areas that were still relatively open during that time period and are thus more likely to potentially harbor restorable remnants today, even if land use data in 2000 shows them having a closed canopy.

Other variables, such as SSURGO-certified digital soil maps would likely have been beneficial in the model but were not available for all counties. However, the most important soil differences were captured in land use mapping of different vegetation types. This was partially due to the inherent nature of vegetation patterns responding to soil differences on the landscape, but also because soil maps were one variable used in delineating circa 1800s vegetation (Comer et al. 1995). Other variables such as the National Wetlands Inventory (NWI) were also evaluated, but were determined to be redundant for similar reasons.

The second model targeting areas for potential grassland creation was also compiled using land use data from 1800, 1978, and 2000. Sites with an intensive agricultural land use (row crops) in 1978 and 2000 were identified in areas historically dominated by prairie and savanna. In addition, pine plantations, which represent a small but significant restoration opportunity in some regions, were also included in the creation model.

Methods

Restoration Model

A model was constructed using a combination of land use grids and a polygon shapefile of MNFI element occurrence data. All layers were assigned a weight for their overall contribution. Land use change 1800-2000 was given a higher weight (2/3 of total score) than land use 1978 (1/3 of total score) (Table 2). Within each layer, each attribute was also weighted according to its overall importance within the layer (Tables 3 and 4). The attribute rank was then multiplied by the layer weight to generate a cell weight. Once all layers were weighted they were added together, resulting in a grid of restoration potential. All weights were determined using expert knowledge and experience.

Weighting factors for land use change were based on the percentage of each change category occurring in prairie and savanna element occurrences. To calculate this variable, prairie and savanna natural communities were identified and corresponding element occurrence polygons were selected from the MNFI database, creating a new polygon shapefile. Next, an intersection was performed between this EO shapefile and a grid of land use change from circa 1800 to 2000. For each land use change category, the percentage of grid cells that occurred in EO polygons was determined. Land use change categories were then sorted from highest to lowest, and broken into six categories based on natural breaks, the standard ArcView classification scheme. These categories were reclassified and assigned a weight value for the model (Table 3).

Weighting factors for land use in 1978 were based on Anderson level 1 and level 2 categories. Natural open areas (herbaceous open land, shrub land, savanna, barren ground, and open wetlands) were given a maximum weight, while other natural areas (forests, wetlands, water) were given a minimal weight (Table 4).

In addition, grid cells with land uses of urban and intensive farmland (row crops and Christmas tree plantations) in either 1978 or 2000 were eliminated from the model. Finally, the model was split into uplands and wetlands based on circa 1800 land use.

Table 2. GIS layers used in restoration model.

Restoration Model Layers	Layer Value	Layer Weight
Land use change 1800 - 2000	10	0.667
Land use 1978	5	0.333
Total	15	1.000

Table 3. Weights used in GIS model for land use change from circa 1800 to 2000.

Percentage of cells in high-quality sites	Attribute Value	Attribute Weight	Cell Weight
4.1-15%	5	1.000	0.667
1.8-4.1%	5	1.000	0.667
0.9-1.8%	3	0.600	0.400
0.34-0.9%	2	0.400	0.267
0.07 - 0.34 %	1	0.200	0.133
0.00001 - .07 %	0	0.000	0.000
Number of different categories	5		

Table 4. Weights used in GIS model for land use in 1978.

Land use 1978	Attribute Value	Attribute Weight	Cell Weight
Open land (herbaceous openland, savanna, open wetlands, barren ground)	2	1.000	0.333
Other natural cover (forests, wetlands, water)	1	0.500	0.167
Number of different categories	2		

Creation Model

The creation model was generated using a combination of land use in 1800, 1978, and 2000. First, circa 1800s land use categories that corresponded to prairie or savanna were identified and selected (Table 5). From 1978 and 2000 land use, intensive agricultural land uses (row crops) were selected. In addition, sites with Christmas tree and other pine plantations were selected. Finally, a GIS intersect was conducted between prairie and savanna land use circa 1800 and intensive agriculture and pine plantations, generating a resulting grid of potential creation sites.

Table 5. Circa 1800 prairie and savanna land use categories used in creation model.

Covertype	Percentage of state
Black oak barren	1.93
Grassland (upland prairie)	0.20
Mixed oak savanna	2.85
Oak/pine barrens	0.30
Pine barrens	0.73
Wet prairie	1.03
Total	7.04

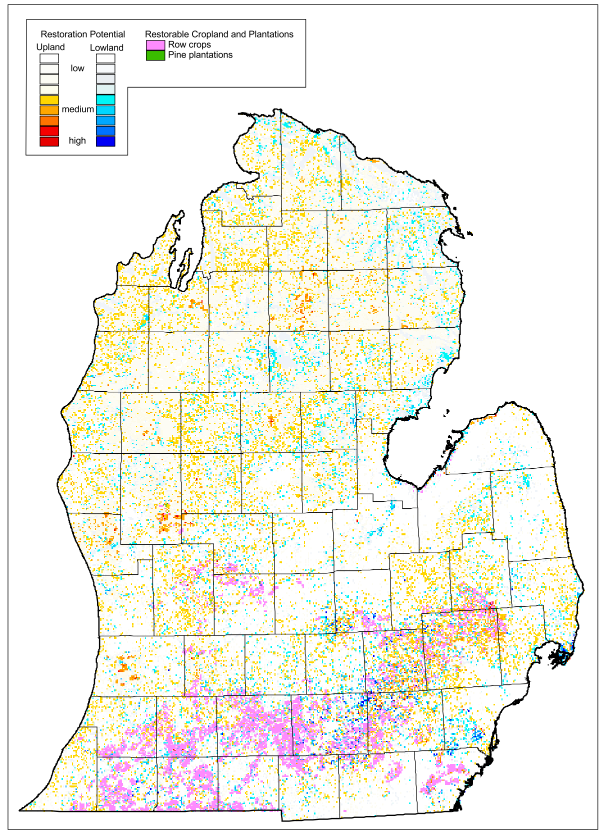

Figure 1. Prairie and savanna restoration potential in Lower Michigan based on GIS modeling.

Results and Discussion

Utility and examples

Both field-based approaches and GIS models can be used to identify restoration focus areas at state, regional, and local levels. The benefits of prioritizing work with the highest potential to have a positive impact include allowing scarce resources to be utilized more effectively, facilitating easier decision-making when restoration opportunities arise, and increasing the likelihood of accomplishing ultimate goals of restoring healthy populations of species.

From a statewide perspective, it must be recognized that particular regions have greater potential to harbor remnant prairies and savannas and provide suitable habitat for associated rare and declining species. The same key regions of the state were identified in both the GIS model and in more traditional maps used in planning such as the extent of prairie and savanna circa 1800 and the location of EOs associated with such habitats. These areas include the Kalamazoo Interlobate (portions of Van Buren, Cass, Barry, Kalamazoo, St. Joseph and Calhoun counties); the Jackson Interlobate (portions of Jackson, Washtenaw, Livingston, Oakland and Lapeer counties); the Lake Erie Lakeplain (portions of Wayne and Monroe counties); the Newaygo Outwash (portions of Newaygo and Lake counties) as well as adjacent areas in Muskegon, Montcalm, Kent, and Allegan counties; and the Highplains Region (portions of Crawford, Oscoda, Alcona, Otsego, and Montmorency counties) (Figures 1-3). The model results were closely related to the historical distribution of prairies and savannas, as expected due to the inclusion of this variable into the model (Figure 2). Although rare species were not included in the model, they are closely associated with these regions (Figure 3), strengthening the argument for prioritizing these areas. From a statewide perspective, regions identified in the model were similar to those that might be identified using traditional approaches such as maps of historical distribution of prairies and savannas and locations of associated rare species.

Within these regions, priority landscapes can be further refined to better assess the potential for restoration. At this scale, prioritization objectives include identifying important landscapes as well as linkages between them. For example, within the Newaygo Outwash region, one might select three or four key local areas based on restoration potential, opportunities to connect isolated landscapes with large corridors, and known locations of rare species. At this scale, the model may

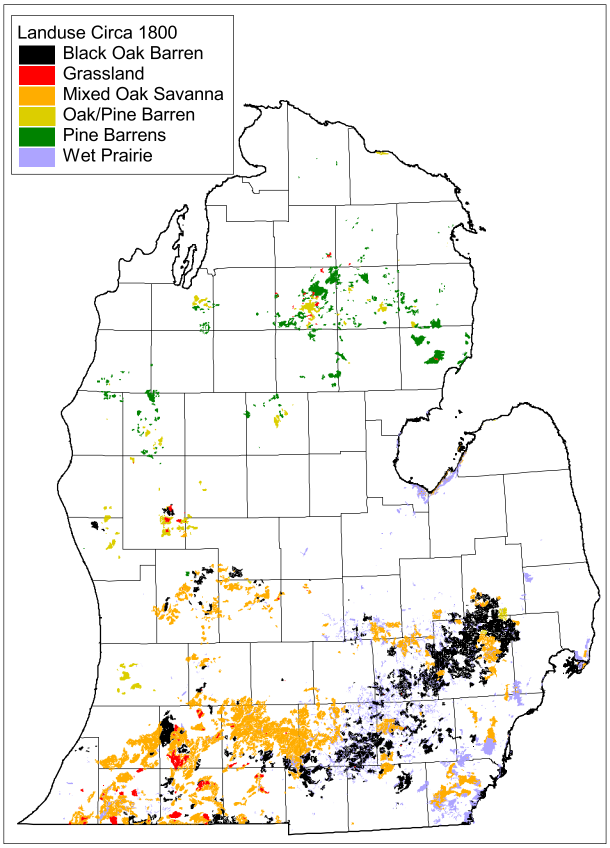

Figure 2. Prairie and savanna distribution circa 1800.

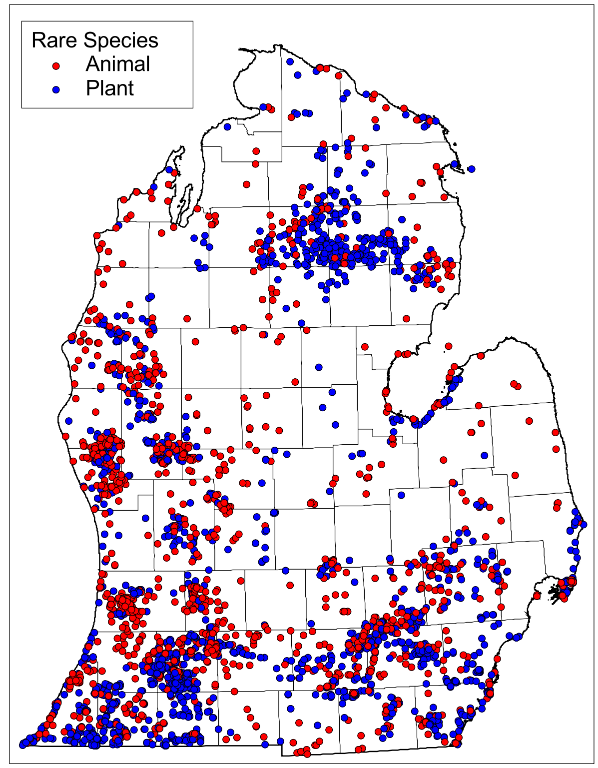

Figure 3. Occurrences of rare species associated with prairies and savannas in Lower Michigan.

find its maximum utility when compared with other approaches, since maps of current landcover may not provide sufficient data on historical distribution or site restorability and aerial photos, while very useful at smaller scales, are nonetheless too fine to be of practical use at regional scales.

At the local scale, both the restoration model and traditional approaches such as aerial photo interpretation can provide information on site prioritization. An area in Brooks Township, Newaygo County provides an ideal location to examine the utility of the model at a fine scale. Based on the model, sites in dark red have the highest potential for restoration, followed by sites with progressively lighter shades of red and orange (Figure 4). Spatially, these high-potential areas can be grouped into larger blocks and corridors can be identified that might link up an otherwise fragmented landscape. Overlaying key rare and declining species can provide additional critical information. In this example, recent observations of a rare insect help identify sites with the highest management priority. Additionally, locations of key species can be used to help determine larger effective management units. Instead of restricting management activity (such as prescribed burns) to small, fragmented habitat patches amounting to just a few

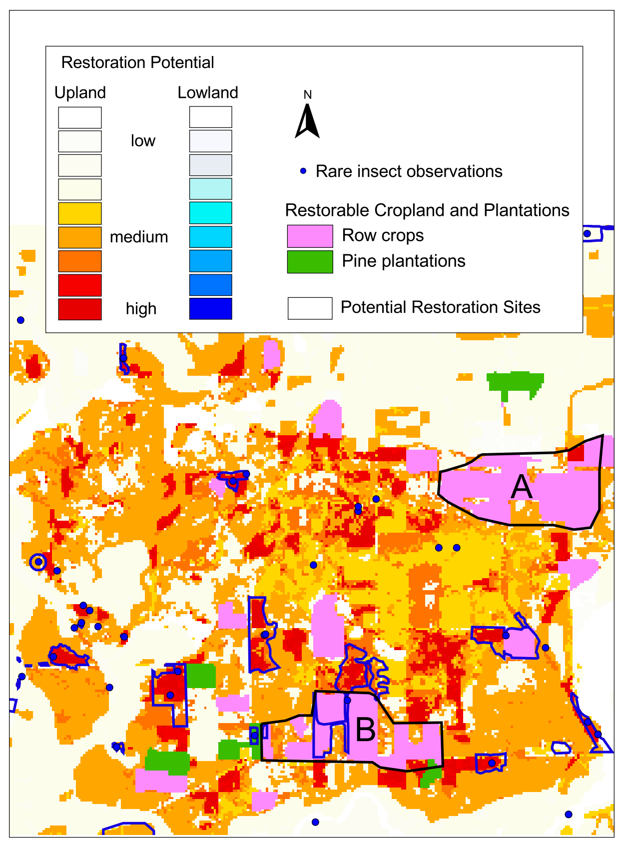

Figure 4. Prairie and savanna restoration potential in Brooks Township, Newaygo County.

acres, restoration can target several hundred acres of adjacent habitat in addition to a portion of occupied habitat.

Both high-potential restoration sites and rare species observations can also be used to target potential former agricultural land for restoration. Resource-intensive projects like planting grassland or clearing old pine plantations should be done in close proximity to remnant habitat where they can meet multiple objectives. In the Brooks Township example, a large field restored to prairie at site A might make for good grassland bird habitat but have little benefit to other species. Alternatively, if fields and plantations in and adjacent to site B were restored they could potentially benefit birds as well as local populations of rare and declining insects. More importantly, functional metapopulations of rare species could be established by linking up otherwise isolated populations.

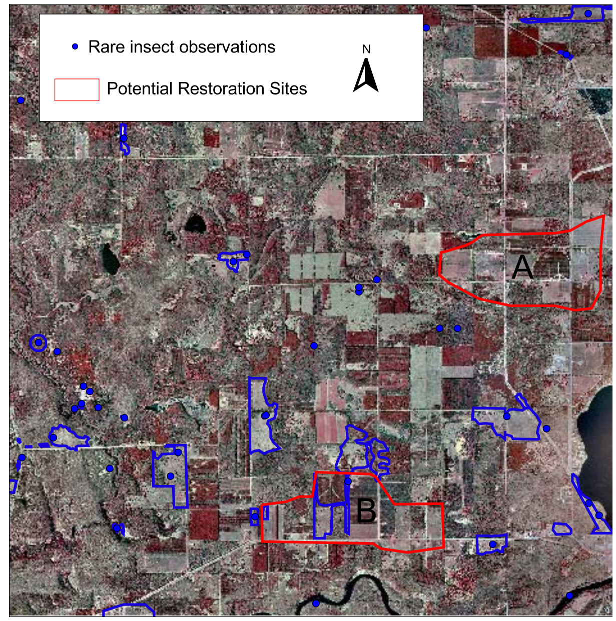

Figure 5. 1998 color-infrared aerial photo of a portion of Brooks Township, Newaygo County. The photo covers the same area shown in Figure 4.

Compared with the model, expert interpretation of an aerial photo can yield far more detailed information on current vegetation and potential restorability. Areas in pink in Figure 4 represent sites classified as row crops in 1978. These areas may represent key restoration opportunities, or, if since abandoned, may already be recovering with native vegetation. In comparing the same local landscape as displayed in the model with the aerial photo, it is clear the model oversimplifies the parameters affecting the potential success of a restoration project, especially related to current woody cover and amount of coniferous vegetation (Figure 5). In general, a combination of aerial photo interpretation and field surveys may provide much more specific information to land managers on current site conditions and restorability.

<u>Evaluating the effectiveness of the model</u>
The restoration model was not tested statistically or ground-truthed beyond qualitative observations at select sites. For this reason, it should be considered a tool to be used with caution in conjunction with other data.

In general, the user should be aware of several important issues regarding the model's application. First, it should be noted that because the model is based on the spatial area occupied by community element occurrences, it is heavily biased towards those communities for which abundant data are available, both in terms of the number of EOs and the spatial extent they occupy. Communities over-represented in the model include prairie fen, oak-pine barrens, and pine barrens. Communities for which no or very little data existed and are thus very under-represented include oak openings, bur oak plains, and a variety of prairie types (mesic prairie, woodland prairie, etc.).

Second, it must be noted that the main factor used in scoring an area's restorability, the likelihood of a given change category to fall in a high-quality site, was very low (often one to two percent, at best). In general, the absolute value of the model score is less important than the score relative to the surrounding landscape. Finally, questions regarding the accuracy of the source data must be considered. Gross discrepancies exist between the scale at which the vegetation data was collected and the resulting accuracy at any given site. The circa 1800s data, based on coarse-level sampling along section lines one mile apart and interpolated in between, is largely considered inappropriate for use at fine scales (less than a township) (Manies and Mladenoff 2000). In the model, this coarse-level data is compared with satellite data collected in the year 2000 at 30 meter grid cells. This data has its own biases, and is likely to only represent the dominant canopy and not the vegetation beneath. For example, a remnant oak savanna with an 80% canopy closure is likely to be classified as a forest. Similarly, a remnant prairie fen succeeding to shrub carr due to fire suppression is likely to be classified as a shrub wetland, even though fen vegetation may still exist beneath the shrub canopy. Furthermore, the accuracy of the year 2000 land cover for the classification used in the model ranges from 36% to 87% depending on the category (Donovan et al. 2004). Thus, between the differences in scale and the problems with accuracy, significant problems exist with the land use change data, and the likelihood of any one grid cell representing the actual land use change may be small.

In some cases, however, the model actually takes advantage of these discrepancies in spatial sampling. For example, several land use change categories that ranked surprisingly high were those that indicated a change from oak savanna and forest to open wetlands. Such a drastic change from upland to wetland is unlikely to have actually occurred and is more likely the result of comparing GIS layers created at different spatial scales. This discrepancy in the data should not be completely disregarded, as it may reflect real ecological patterns, such as the tendency of high-quality prairie fens and wet prairies to be located in close proximity to oak savannas where groundwater seepage wetlands emerge from the bases of dry oak-dominated hills with coarse, calcareous soil.

Despite occasionally highlighting interesting ecological patterns, the data behind the current model are sufficiently inaccurate that strong cautions are warranted to those looking for a quick GIS-based solution to prioritizing restoration potential. As better data becomes widely available in the future, modeling may yield better results. Especially useful data sets may include statewide SSURGO (Soil Survey Geographic) data from the USDA Natural Resources Conservation Service (NRCS). At this time, detailed spatial and tabular soil data is complete for approximately 95% of counties in Lower Michigan, with the remainder of counties expected to be completed in the near future. Additional useful data would include high-resolution remote sensing data for current land use and vegetation cover, as well as information on the herbaceous layer beneath the canopy, which may become more available as canopy-penetrating sensors become more refined and economical.

At the current time, restoration and management cannot be guided by GIS models alone. Until better, more accurate models can be developed, we suggest utilizing a combination of approaches including current models as well as traditional approaches such as historic land use, aerial photo interpretation, and field surveys. The latter are especially stressed since only field observations can detect critical indicators of restoration potential like remnant herbaceous communities of prairie grasses and wildflowers and open grown “wolf trees” in now-closed canopy oak forests. More detailed information on field-based indicators of remnant prairies and savannas and on-the ground guides to assessing restoration are widely available in current published literature (Packard and Mutel 1997).

Conclusions

Overall, the model should be viewed as a useful but untested planning tool. It might be best used in conjunction with known distributions of species, other field data, and knowledge of local biologists to identify potential areas for restoration, followed by field surveys to verify the potential suitability of those areas to respond to management.

The restoration model and traditional tools can be used to identify focus areas for restoration and conservation at multiple spatial scales, ranging from statewide to regional to local levels. Prioritizing efforts in areas with the highest potential will allow scarce resources to be utilized more effectively, facilitate easier decision-making when restoration opportunities arise, and increase the likelihood of restoring healthy populations of species.

In general, it is recommended that land managers pay special attention to restoring connectivity between fragmented habitat patches. A shift in scale from managing small remnants and planted grasslands a few acres in size to managing large fire-dependant landscapes several hundred acres or larger is also suggested. In addition, the location of new grassland creation sites should be based on proximity to other remnant habitats, and be located in regions historically dominated by prairie and savanna if they are to fulfill multiple benefits to a variety of declining species. Finally, biologists are strongly encouraged to use expert field knowledge to bolster restoration planning efforts for oak savanna communities that may be poorly predicted by the model.

Acknowledgments

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