An Automated Approach to Site Selection in Fragmented Landscapes

Using the AutoPASS method to determine the optimal lands for reforestation in the Baraboo Hills Forest of Southcentral Wisconsin

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Research Theory: The AutoPASS Method

1. Introduction:

Habitat **fragmentation** is a process of dividing a discrete, homogenous habitat into smaller, isolated patches and has been identified as one of the most important factors causing the loss of native species and habitat instability. A heavily fragmented landscape negatively affects its inhabitants by increasing competition, predation, and parasitism while decreasing nutrient quality and resource availability. Many species experience higher survival and reproduction rates in large tracts of contiguous habitat with few edges. For these species, there is a minimum area threshold for a patch within which they can survive, confining them to only the interior areas of the patches and further reducing the area available for their habitat. **Interior area**, or core area, are lands far enough removed from the edge so that they act as a sanctuary for 'interior sensitive' species. Fragmentation leads to an increase in the proportion of habitat within these detrimental edges relative to the interior area (Figure-1a and Figure-1b). For the above reasons, ecological restoration of core-dwelling species should focus on decreasing fragmentation while increasing interior area, rather than just generating the largest gross increase in land.

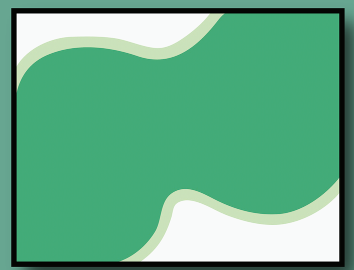


Figure-1a: A healthy habitat patch, where a large percentage of the habitat (shown in green) is interior.

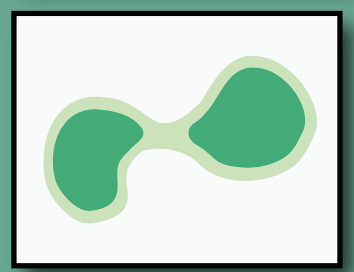


Figure-1b: The same patch after fragmentation. The interior area versus the edge area (shown in tan) are now nearly equal. Although the patch is still contiguous, the interior sections have been isolated, further reducing the available habitat for interior-sensitive species.

2. Compactness as a Foundation:

Few techniques offered in the literature provide quantitative ways to analyze and eventually alleviate problems associated with fragmentation and reduced interior area. Without a standard metric with which to evaluate the effectiveness of certain ecological restoration sites, managers have relied, often solely, on the much-maligned visual interpretation method to prioritize the specific sites to be restored. The proposed method, referred to as **AutoPASS** (*Automated Patch Analysis for Site Selection*), addresses these concerns by analyzing the spatial characteristics of patches using GIS (Geographic Information Systems) techniques, resulting in a quantitative prioritization of the potential ecological restoration sites based on their capability to reduce fragmentation and increase interior area.

Comparing the degree of fragmentation to the amount of interior area is really an analysis of geometric shape, in which the shape's perimeter is compared to its area. A very common equation used to quantify the relationship between perimeter and area is **compactness**, sometimes called relative edge. Patches that are more 'compact' will exhibit a lesser degree of fragmentation, and therefore have a larger perecentage of their total area dedicated to interior area. We have incorporated the principles of compactness into a **convolution** stategy, or moving-window analysis, to assess the relative influence of a site on the compactness ratio of the overall patch, producing a metric with which to quantitatively prioritize the restoration of sites on a landscape. Figure-2 illustrates the moving window analysis.

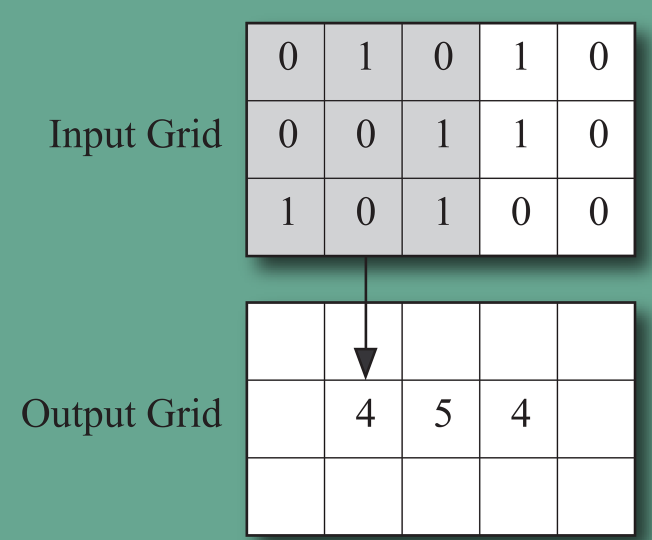


Figure-2: In this example moving-window analysis, the values in the three-by-three window in the input grid are added to produce a new value for the center pixel of the output grid. This kernel passes throughout the entire image, generating the complete output grid.

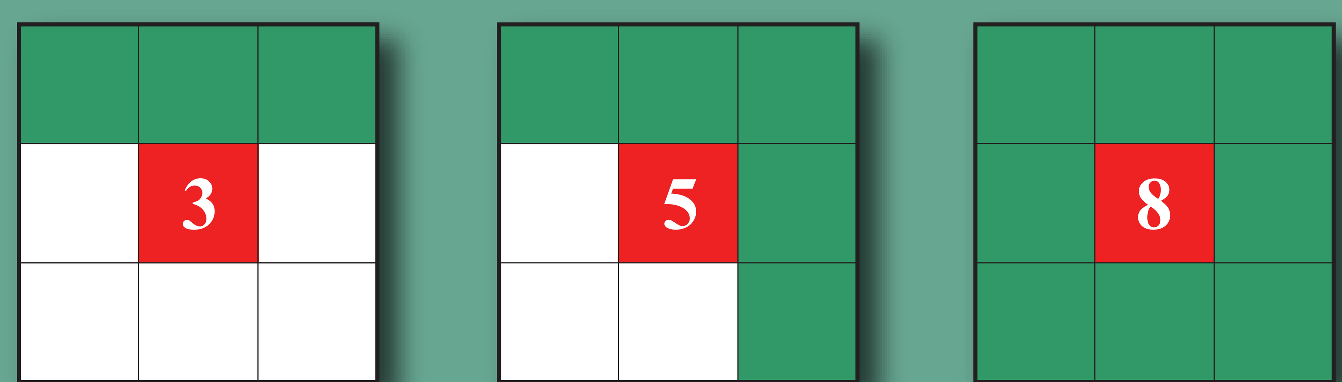
3. Example AutoPASS Prioritizations:

There is a direct relationship between the compactness value of a patch and the digital number placed in the center of the kernel during the convolution. In Figure-3a, three patch pixels are within the 3x3 kernel, meaning the convolution will place a '3' as the digital number in the center pixel on the output grid. If this pixel is integrated into the patch, two sides of perimeter are added, while adding one unit of area. Because both the area and perimeter increase, the numerator and denominator also would increase in the compactness ratio, causing marginal change to the ratio.

In Figure-3b, the center pixel receives a '5' as the digital number from the convolution because there are five pixels within a patch inside the kernel. In this case, the addition of the center pixel would not add additional perimeter, yet still add one unit of area. In terms of the compactness ratio, the denominator is now unchanged, while the numerator is increased, thus improving the compactness ratio. Restoring this pixel will have a better effect on the compactness ratio than restoring the pixel in Figure-3a.

Finally, in Figure-3c, the center pixel receives a value of '8'. This is the ideal case because the addition of one unit of area occurs while four sides of perimeter are eliminated. The area increases while the perimeter is reduced, having a significant effect on increasing the compactness ratio. Thus, integrating this pixel into the patch should be a greater priority than restoring the pixels from Figure-3a and Figure-3b. Because the compactness ratio is linked to the amount of fragmentation and interior area, restoring the pixels with higher digital numbers from the convolution will reduce the fragmentation and increase the proportion of interior area at a more desirable rate than pixels with lower digital numbers.

Figure-3: In these kernel examples, the white pixels represent areas not within a patch (value of '0'), the green pixels represent areas within the patch (value of '1'), and the red pixel represents the prospective cell for ecological restoration that is currently not within the patch (also given a value of '0').



Case Study: The Baraboo Hills Forest

4. The Baraboo Hills Forest and The Nature Conservancy:

The Baraboo Hills Forest, located in the state of Wisconsin's Sauk County (Figure-4), is a unique landscape due to characteristics of the underlying bedrock. The bedrock, known as Baraboo quartzite, is incredibly dense, remaining largely unaltered throughout past glaciations. This ancient parent material is associated with a distinct set of landscape elements, contributing to its diverse flora and fauna. Currently, the Baraboo Hills possess the largest remaining forest block in Southern Wisconsin at nearly 10,000 hectares, providing a natural habitat to over 1,800 different species. Unfortunately, throughout the 19th century, and especially in the first half of the 20th century, this area experienced intense deforestation and habitat degradation. Increased agricultural activity and development in the area have severely fragmented the forest block. In recent years, the region has begun to rebound in forested area due to shifting land use patterns, allowing focus to be moved from the reduction of ultimate causes of fragmentation to active reforestation. The Nature Conservancy, a non-profit conservation organization involved in the area, has adopted an initiative to begin this active reforestation.

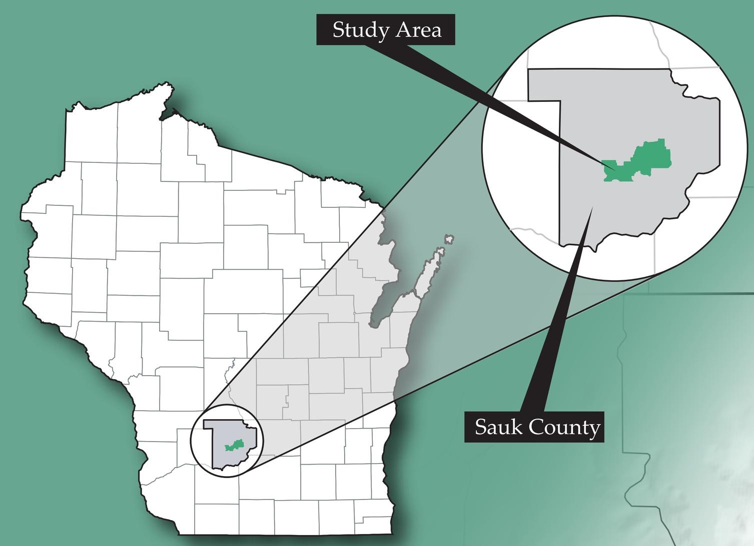
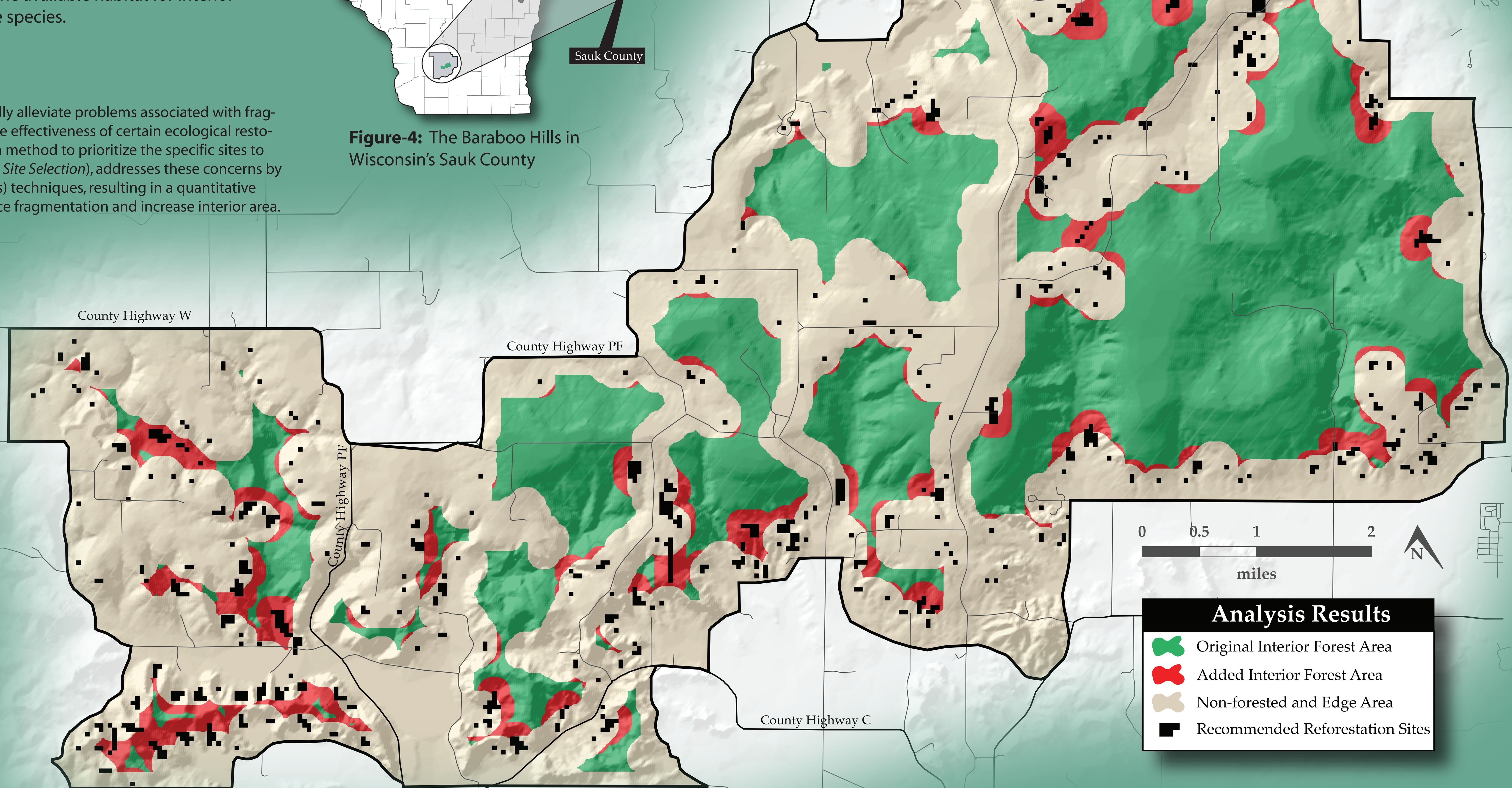


Figure-4: The Baraboo Hills in Wisconsin's Sauk County



Results and Discussion of the Application

5. Integration of Domain Knowledge:

A major advantage of the AutoPASS method over other methods is that it allows domain knowledge to be integrated into the prioritization by multiplying weightings against the original shape prioritization using a raster calculator. Two types of weightingss are identified: **exclusionary** (any factor that decreases the importance of restoring a site) and **multiplicative** (any factor that increases the importance of restoring a site). Because the Baraboo Hills Forest restoration effort was focused primary towards protecting the interior-sensitive songbird species, the following domain knowledge about these songbirds was incorporated into the prioritization grid. Figure-5a and Figure-5b show the spatial distribution of the domain knowledge incorporated in the case study. The weighting values themselves were determined by field experts with The Nature Conservancy.

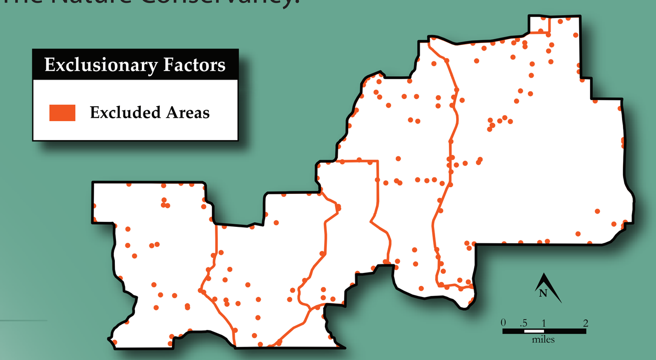


Figure-5a: Exclusionary Factors
(1) forest seeds that are less than 160 acres
(2) areas within 50 meters of roads or power lines
(3) areas within 50 meters of houses or developed areas.

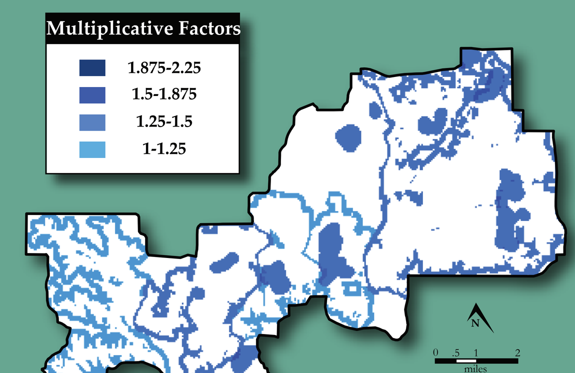
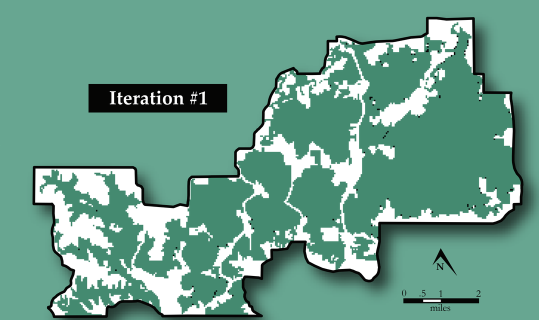


Figure-5b: Multiplicative Factors
(1) areas near a high diversity habitat
(2) the relative suitability of each existing forest seed

6. Iterative Site Selection:

The AutoPASS method works iteratively by reincorporating sites above a **critical value** into the forest grid at the end of each convolution. If no domain knowledge is incorporated into the analysis, the critical value should be above '7' to avoid ambiguous pixel signatures. However, if domain knowledge is incorporated, this value needs to be adjusted accordingly. The method continues with iterations until one of two situations occurs: (1) the amassed pixel area reaches the total acreage that can be restored based on the project budget or (2) there are no longer any pixels above the chosen critical value. The case study used a critical value of '6.25' due to the inclusion of domain knowledge, and recommended a total of 950 acres for restoration over the course of ten iterations.

Figure-6a: Iteration #1
This image shows the initial iteration, with the existing forest shown in green and the suggest sites in black



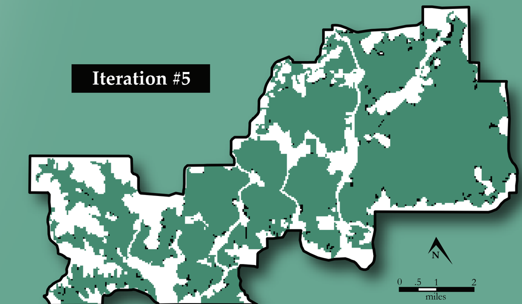
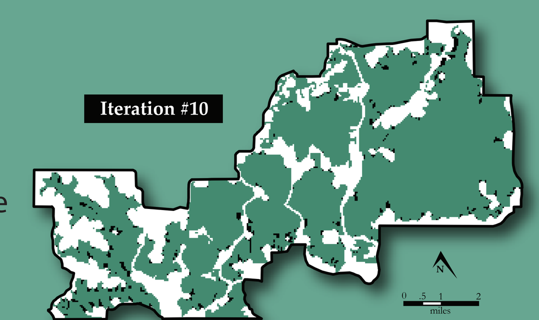


Figure-6b: Iteration #5
By the fifth iteration, many of the medium sized openings on the eastern side of the forest were filled

Figure-6c: Iteration #10
By the final iteration, large gaps in the southwestern side of the forest were filled.



7. Evaluation of the Application:

The effectiveness of the AutoPASS method can be determined in three ways:
(1) the change in degree of fragmentation using the compactness ratio
(2) the increase in total interior area compared to the increase in total area
(3) the increase in interior area per unit area that was suggested for reforestation

(1) Change in Fragmentation:
The suggestions from the AutoPASS method successfully decrease the perimeter by 17.23% by increasing the total area only 3.68%. The resulting changes improve the compactness ratio from 0.08989 to 0.11269, a surprising 25% increase.

(2) Interior Area Increase versus Total Area Increase
As previously mentioned, restoration of the 950 suggested acres only increases the total forested area by 3.68%, but does wonders for the interior area, increasing it a full 19.91%. Further, by incorporating the AutoPASS suggestions, the percentage of the forest dedicated to interior area would increase from 48.19% to 55.51% (now making the interior area the majority).

(3) Interior Area per unit Reforested Area
Perhaps the most interesting finding is that it only took the restoration of 950 acres to achieve an improvement of 2,227 desired interior acres. The concept of increasing the acreage of interior area beyond the actual acreage planted is an important economic advantage of the AutoPASS method. We are essentially getting 235% more bang for our buck, saving approximately 57 cents on the dollar. The center image contrasts the added interior with the sites recommended for reforestation.

Table-1	Before	After	Change	%Change
Perimeter of Forest Patches	238 mi	197 mi	41 mi	-17.23%
Total Area of Forest Patches	23,215 acres	24,165 acres	950 acres	+3.68%
Interior Area of Forest Patches	11,187 acres	13,414 acres	2,227 acres	+19.91%
Interior Area as % of Total	48.19%	55.51%	7.32%	+15.19%
Fragmentation (compactness)	0.08989	0.11269	0.0228	+25.36%

*Special thanks to Professors A-Xing Zhu and Mark Harrower, Certificate Student Eric Holbus, and The Nature Conservancy of Madison