An Automated Approach to Site Selection for Ecological Restoration in Fragmented Landscapes

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Abstract
Reducing fragmentation and increasing interior area of habitat patches are major goals of restoration programs. Most strategies to correct these issues are qualitative based on visual interpretation, rather than quantitative based on the spatial characteristics of patches. To circumvent this, we developed an approach that integrates domain knowledge into an objective and geometric analysis of the spatial characteristics of patches. A prioritization grid is then generated from this approach and used to evaluate prospective ecological restoration sites based on their capability to decrease fragmentation and increase interior area. An application of the method indicated a 25% improvement of the compactness ratio and overall saving of investment in restoration efforts.
Keywords
GIS, convolution, habitat fragmentation, interior area, ecological restoration

I. INTRODUCTION

Urban development, deforestation, and agricultural activities change landscapes in various ways, but one thing is clear, when human beings alter the natural landscape, they fragment it (Marzluff and Ewing, 2001). 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 (Harris ,1984; Wilcox and Murphy, 1985; Wilcove et al., 1986; Andrén, 1994). A heavily fragmented landscape negatively affects its inhabitants by increasing competition, predation, and parasitism while decreasing nutrient quality and resource availability (Marzluff and Ewing, 2001). Furthermore, consistent with the classic island biogeography theory, fragmentation produces barriers that impede community interactions among different patches (MacArthur and Wilson, 1967).

Many species experience higher survival and reproduction rates in large tracts of contiguous habitat with few edges (Temple and Cary, 1988). For these species, there is a minimum area threshold for a patch within which they can survive (George and Zack, 2001). Also, the conditions at the edges of these patches are often hazardous due to the increased predation and parasitism (Temple and Cary, 1988; Marzluff and Ewing, 2001). As a result, species are confined to only the interior areas of the patches, 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 (Temple, 1986; Marzluff and Ewing, 2001). Interior area has been defined as the center area of the patch that lies at least 50-200 meters from the edge (Soulé, 1991; Shafer, 1997). Fragmentation leads to an increase in the proportion of habitat within these detrimental edges relative to the interior area (Temple, 1986). For the above reasons, ecological restoration of core-dwelling species should focus on decreasing fragmentation while increasing interior area.

Ecological restoration plans should consider how newly restored areas could maximize the increase of interior area by considering the existing spatial patterns of the landscape. Unfortunately, most approaches to ecological restoration design are unable to effectively maximize the increase of interior area due to the insufficient consideration of the spatial characteristics of habitat patches. In addition, the qualitative nature of existing approaches in the form of expert recommendations makes consideration of the spatial nature of patches subjective (Baskent, 1999; Scott et al., 2001). Few techniques offered in the current literature provide quantitative ways to analyze and eventually alleviate problems associated with fragmentation and reduced interior area (Baskent, 1999; Marzluff and Ewing, 2001). Without a standard metric with which to evaluate the effectiveness of certain ecological restoration sites, managers have relied, often solely, on conventions to prioritize the specific locations to be restored without considering the spatial context of the site (Rettie and Messier, 2000).

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. By restoring sites with the highest priority, the landscape will become less fragmented with a greater relative amount of interior area for the targeted, core-dwelling species. The next section describes the details of

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the AutoPASS method. The third section describes the application of this method in the Baraboo Hills of Wisconsin as a case study. The results of this case study are presented in the fourth section. Discussions and conclusions are made in the fifth and final section.

II. METHODS

A. Compactness as a foundation

Maximizing the interior area while minimizing the perimeter of a patch is central to ecological restoration (Marzluff and Ewing, 2001). Both interior area and perimeter are interrelated spatial concepts. A very common equation used to quantify the relationship between these two concepts is compactness, sometimes called relative edge (MacEachren, 1985; Cain et al., 1997; Baskent, 1999). Although the specific definition for this term varies among sources, it is always a ratio of the area to the perimeter. Equation 1 shows the compactness ratio

$$C = \frac{\sqrt{Area}}{0.282 Perimeter}$$

where C is the compactness value (ranging from 0 to 1). A shape with a larger area relative to its perimeter will be more compact, having less fragmentation and a higher proportion of its area dedicated to the interior. The ideal shape, in terms of compactness, would be a circle (having a compactness value of '1') and the least compact shape is a line (having a compactness value of '0'). An example edge that would yield a poor compactness ratio would be the highly jagged coastline of the state of Maine in northeastern United States.

However, applying compactness as the sole determinant for site selection presents two major drawbacks. First, and most importantly, the compactness ratio is a summary statistics; it will only show if a change is better or worse. It will never to improve predict exactly where the shape should be altered predict exactly where the shape should be altered to improve the ratio. Secondly, when only using compactness to analyze shape, secondary attributes about preference of habitats, which are often drawn from domain specific knowledge, cannot be incorporated into the analysis.

B. Shape prioritization using convolution

A convolution strategy was developed in this study to address the aforementioned drawbacks of the compactness ratio. The AutoPASS method first creates a raster data layer of the study area such that each pixel is given either a value of '0' (for all areas not within the patches) or '1' (for all areas within patches). For example, if the focus was to reduce fragmentation of grassland, all areas not considered grassland would be represented with a '0', while all areas that are grassland would be represented with a '1'. The pixel size should correspond to the minimal ecological restoration unit.

A convolution is then run on the binary grid using a 3×3 window in which the central pixel receives the sum of the values of the 9 pixels (itself and its eight neighbors) within the window, producing a new output grid as shown in Figure 1. Clearly, a pixel that has more neighbors of the desired habitat as covered by the kernel will have a higher value placed in the center than those pixels that have fewer neighbors with the desired habitat. In other words, the output from this convolution process provides information on the spatial context of the pixel in terms of the desired habitat.

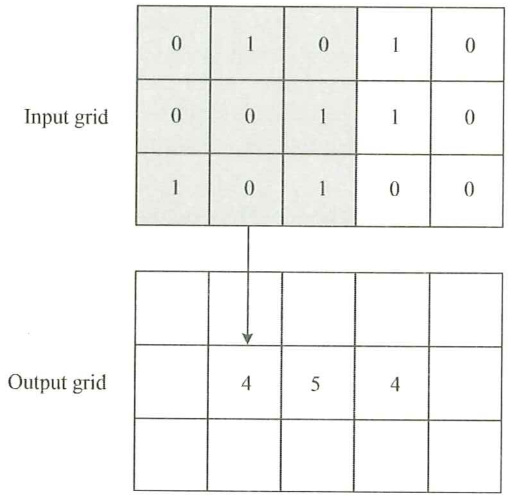
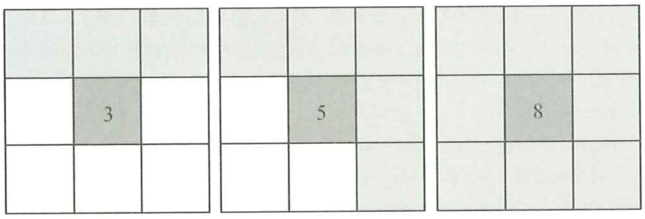


Figure 1. Convolution creates a new grid of values based on the sum within the kernel. The 3×3 kernel adds the values from an input raster grid and places this sum in the center pixel on a corresponding output raster grid. Once complete, the kernel moves one column to the right until the row is finished, then moves down the rows until the entirety of the image is convoluted with the addition coefficients.

There is a direct relationship between the compactness value of a patch and the digital number placed in the center of the kernel. In Figure 2, the white pixels represent areas not within a patch (given a value of '0'), the light grey pixels represent areas within the patch (given a value of '1'), and the dark grey pixel represents the prospective cell for ecological restoration that is currently not within the patch (also given a value of '0'). In Figure 2(a), three patch pixels are within the 3×3 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. The area and perimeter increase, meaning the numerator and denominator would increase in the compactness ratio, causing marginal change.

In Figure 2(b), 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



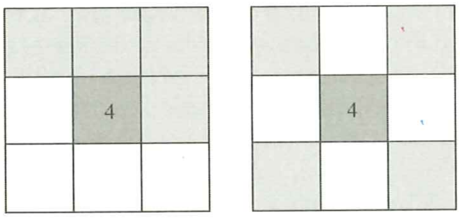
(a) (b) (c)

Figure 2. (a) The three surrounding patch pixels yield a convolution value of '3', increasing both the perimeter and the area, having little effect on the compactness ratio; (b) The five surrounding patch pixels yield a convolution value of '5', increasing the area while leaving perimeter unchanged, improving the compactness ratio; (c) The eight surrounding pixels yield a convolution value of '8', decreasing the perimeter while increasing the area, fully maximizing the compactness ratio.

this pixel will have a better effect on the compactness ratio than restoring the pixel in Figure 2(a).

Finally, in Figure 2(c), 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 2(a) and Figure 2(b). 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.

As a result, the convolution produces a prioritization grid that determines specific areas that should be selected to improve the shape of the patch, something that analyzing compactness alone cannot achieve. The obvious problem is that there can be multiple arrangements within the kernel that do not always produce a consistent change in the perimeter. Both Figure 3 (a) and Figure 3(b) produce the same priority value of '4', but Figure 3(a) leaves the perimeter unchanged while Figure 3(b) adds four sides of perimeter, with both adding one unit area (and thus affecting the compactness ratio differently). Such inconsistency presents challenges for selecting pixels to be



(a) (b)

Figure 3. (a) The four surrounding patch pixels yield a convolution value of '4', adding one unit area while leaving the perimeter unchanged; (b) The four surrounding patch pixels also yield a convolution value of '4', adding one unit area while adding four sides of perimeter

restored. Situations such as Figure 3(b) may be common enough in a heavily fragmented landscape to require greater restriction on the AutoPASS method. In such situations, it is recommended to keep the threshold above '6', as prioritizations of '7' and '8' do provide predictable changes in perimeter. Also, it is for this reason that we only recommend the use of a 3×3 window, as larger window sizes (5×5, 7×7, etc.) produce too many permutations of possible pixel arrangements.

C. Integration of domain knowledge

Although the reduction of fragmentation is one of the most important aspects for choosing ecological restoration sites, domain specific knowledge (in the form of additional factors, secondary attributes, etc.) need to be considered in the decision-making process. These may include, but are not limited to, proximity to important species, proximity to large patches, proximity to certain resources or habitat types, and distance away from barriers to dispersal and movement, such as roads, railroads, power lines, and bodies of water (Anderson et al., 1999; Scott et al., 2001; Heilman et al., 2002). A major advantage of the AutoPASS method over other methods is that it allows the identified multiplicative and exclusionary factors to be integrated into the prioritization through weights (above and below '1' respectively) multiplied against the original prioritization in a raster calculator at each iteration. Thus, a pixel containing the multiplicative or exclusionary factor increases or decreases the importance of restoring that particular pixel. Any domain knowledge that can be quantified can be integrated in this fashion.

The AutoPASS method produces a standard metric with which to evaluate site selection for potential ecological restoration. Once analysis is completed, pixels from the final prioritization grid that are above a predetermined threshold value are added to the original patch data layer. Because a 3×3 window is used, this threshold must be at least above a '6' to ensure positive impact.

It is recommended that an iterative approach in selecting sites for potential ecological restoration should also be taken. The prioritization values from the convolution process depend on the number of pixels of a desired habitat within the kernel. With each iteration this number changes, meaning that pixels with low prioritization values can quickly increases their prioritization values after their respective neighbors are restored in a previous iteration. This further suggests that the prioritization threshold should be high. Iterations should be run until there are no longer pixels above the prioritization threshold or until a maximum area for ecological restoration has been reached.

III. THE CASE STUDY

A. The study area

The Baraboo Hills (Figure 4), located in the state of Wisconsin,

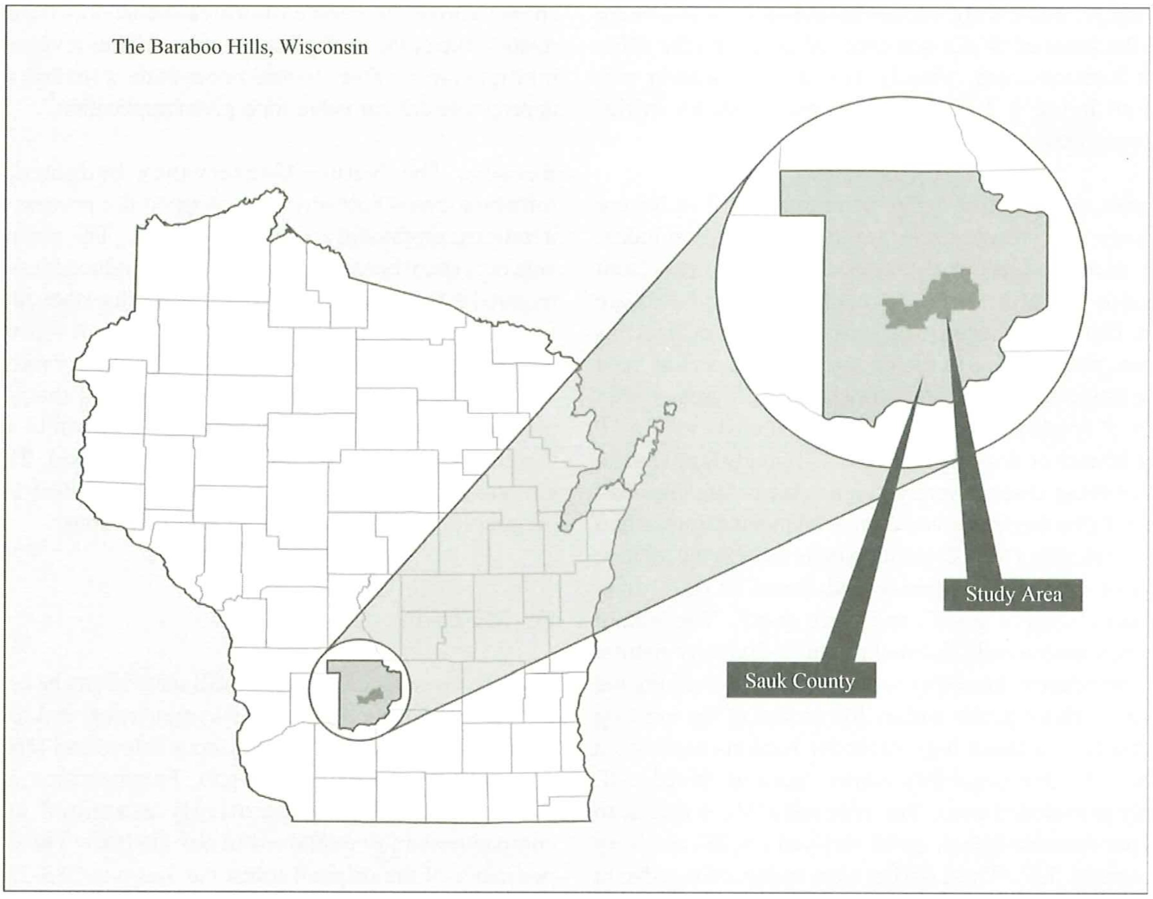


Figure 4. The Baraboo Hills region in Sauk County contains nearly 10,000 hectares of forested land, the largest remaining block in Southern Wisconsin

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.

One of The Nature Conservancy's key interests is the protection of native songbirds in the Baraboo Hills, many of which are endemic to the region. Exotic species have migrated into this area due to the increase of agricultural activity. One of these species, *Molothrus ater*, or the Brown-headed Cowbird, parasitizes the nests of songbirds (Marzluff and Ewing, 2001). Because *Molothrus ater* inhabits open landscapes such as fields and prairies, these birds typically will only penetrate up to 200 meters into the forest to prey upon the songbird nests (Temple and Cary, 1988). Such a relationship is detrimental to native songbird species, limiting their habitation to the interior forest (Whitcomb et al., 1981; Ambuel and Temple, 1983). Many case studies (e.g. Ambuel and Temple, 1983; Blake and Karr, 1984; Barrett, 1995; Bellamy et al., 1996) have shown that songbird populations have a higher rate of survival in larger habitats than smaller ones. Therefore, fragmentation jeopardizes the ability of the songbirds to survive in the Baraboo Hills due to parasitism. The main focus in conserving these songbird species should be on increasing the interior area, not just the overall area.

B. Preparation of raster layers

The Baraboo Hills Study is practical for the implementation of the AutoPASS method due to this importance of habitat fragmentation and interior areas in conservation efforts. Initially, a georeferenced polygon data layer of the forest patches was created by digitizing a 2002 orthophoto at a scale of 1:10 000. This layer was then rasterized into 1 acre pixels, the minimum reforestation unit designated by The Nature

Conservancy. Following earlier discussion, pixels were assigned the value of '0' for non-forested areas and the value of '1' for forested areas. Finally, the raster data layer was convoluted using a 3×3 kernel to establish an initial prioritization index.

At this point, domain knowledge determined by The Nature Conservancy was incorporated into the prioritization index. The three identified factors that excluded certain areas from consideration for reforestation were: (1) forest seeds that are less than 160 acres (where the term 'seed' is defined as contiguous, pre-existing forest of any size that acts as seed stands for future forest-species colonization), (2) areas within 50 meters of roads or power lines, and (3) areas within 50 meters of houses or developed areas. All pixels that meet at least one of these criteria were given a value of '0'. The two factors identified that improved certain areas for reforestation were: (1) areas near a high diversity habitat and (2) the relative suitability of each existing forest seed, based on the ordinal scale of 'poor', 'fair', 'good', and 'very good'. The Nature Conservancy exclusively defined the high diversity habitat areas and the relative suitability scores, as well as defining the term 'near' as those pixels within 200 meters of the existing patch. Pixels near these high diversity habitats received a weight of '1.5'. For suitability scores, 'poor' received a '0' (effectively an excluded area), 'fair' received a '1' (no change to the initial prioritization index), 'good' received a '1.25', and 'very good' received a '1.5'. These indices were multiplied together in a raster calculator so that pixels within 200 meters of a high diversity habitat and within 200 meters of a forest seed with a 'very good' suitability rank would have a multiplicative score of higher than '1.5' (in this case, a value of '2.25').

C. Site selection from the final prioritization grid

Both the exclusionary data layer and multiplicative data layer were multiplied against the prioritization index produced by the convolution using a raster calculator, creating a layer of new prioritization values based upon both the geometric structure of the landscape and domain knowledge. Any pixels within the exclusionary layer reduced the prioritization value to '0' and any pixels within the multiplicative layer amplified the initial prioritization value beyond '1'. Before particular pixels could be selected, the existing forest cover was cropped from the layer because it was already forested and therefore ineligible for reforestation.

The result of these operations was the final prioritization grid from which particular pixels were selected for reforestation based on their values. We chose the value of '6.25' as our critical value based on the above discussion of predictability with values of '7' and '8'. By selecting the threshold at '6.25', a pixel with a convolution index of '4' was not chosen unless it contained both multiplicative criteria. Similarly, a pixel that held none of the multiplicative criteria must have the predictable convolution index of '7'. All pixels at or above this critical value were selected and exported to a new raster file containing all suggested pixels. As shown above the choice of critical value was based on the relationship of the multiplicative indices. Thus revision of these multiplicative values would necessitate a reanalysis of the appropriate critical value for a given application.

Because The Nature Conservancy budgeted for the reforestation of 800 acres, we stopped the process after ten iterations, producing a total of 950 acres. The tenth iteration was necessary because nine iterations produced less than the required 800 pixels. It is important to note that when the existing forest cover was removed for each iteration, it was necessary to also remove the pixels previously selected for reforestation so that they were not reselected. All 950 of the pixels had prioritization values above the critical threshold and were therefore equally eligible according to our method. The Nature Conservancy can select their preferred 800 based on geographic continuity and cost considerations.

IV. RESULTS

The effectiveness of the AutoPASS method can be established by examining the degree of fragmentation and amount of interior forest within the study area before and after adding the recommended pixels to the grid. Fragmentation, a function of shape, can be comparatively examined using the compactness ratio explained in our method. The combined perimeter of the original forest patches was 383,216 meters (238 miles), with a total area of 93,951,797 square meters (23,215 acres). The introduction of our recommended 950 acres reduced the perimeter by 66,012 meters (41 miles) to 317,204 meters (197 miles), while increasing the total area to 97,796 310 square meters (24,165 acres). These findings are consistent with our expectations, which state that as the numerator (area) increases in the compactness ratio, the denominator (perimeter) decreases, causing the compactness statistic to increase. The compactness ratio, originally 0.08989, was improved to 0.11269, a 25% increase.

In order to determine the change in interior area, we removed a setback of 200 meters on both the original forest patches and the updated patches with the 950 pixels incorporated into them. In the original distribution, 48% of the forest was interior, with 45,271,414 square meters of interior area (11,187 acres). Conversely, in the restructured distribution, 56% of the forest was interior, with 54,284,087 square meters of interior area (13,414 acres). Planting the 950 suggested acres would increase the overall forest area by 4%, while at the same time increasing the amount of interior area by 8%.

A final way to assess the success or failure of our method is by looking at the amount of interior area added per unit area that was actually reforested. The goal is that more than one acre will be converted to interior area for every acre of forest added. In many areas within the study region, it is evident that only marginal reforestation was necessary to produce a significant amount of new interior forest, as shown in Figure 5.

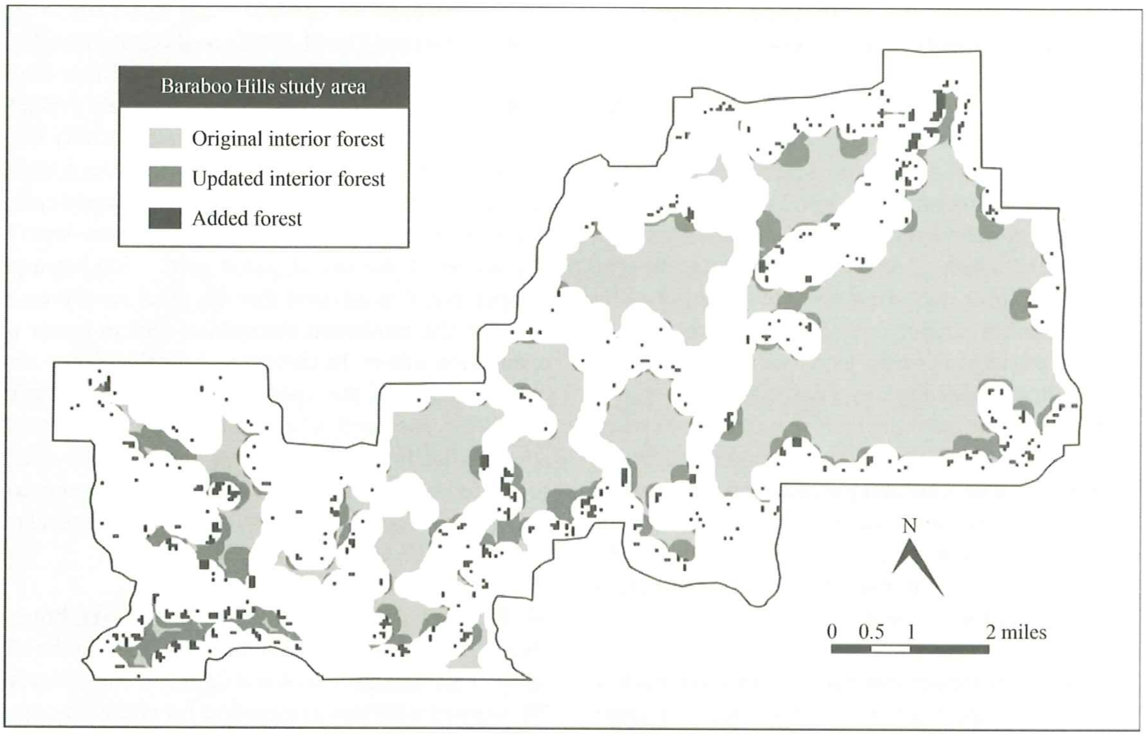


Figure 5. The method improved the original interior area (shown in light grey) by 2 227 acres (in dark grey) by only suggesting 950 new acres for reforestation (shown in black). The area outlined in black is the full Baraboo Hills study area we worked with on our case study. In some areas, especially the far western side of the study area, only marginal reforestation is necessary to significantly increase the amount of interior area

In all, the inclusion of our 950 acres adds a total of 2,227 acres of new interior forest, a 235% increase.

V. DISCUSSION

A. Practical advantages

The concept of increasing the acreage of interior area beyond the actual acreage planted is an important economic advantage of the AutoPASS method. In monetary terms, each acre to be restored costs a set price (with marginal fluctuation from site to site). For example, a single acre may hypothetically cost 1,000 US dollars to restore. Restoring the entirety of our suggested 950 acres would then cost the program 950,000 US dollars to complete. However, as previously established, the focus of the program should be to increase the amount of interior area available for the native species, not simply on increasing the total patch area, as much of it may be wasted by edge predation and parasitism. The ecological restoration of our 950 acres in the case study yielded 2,227 acres of interior area. Thus, by spending the 950,000 US dollars, the program creates 2,227 acres of productive habitat, not 950. The cost per acre now decreases from 1,000 to 426.58 US dollars, saving approximately 57 cents on the dollar. By specifically selecting sites based on their ability to disproportionately increase the amount of interior area, the funds allocated from the total budget are more efficiently and appropriately distributed, allowing a conservation program to literally do more with less.

The relative improvement of desirable habitat is not the sole cost-effective advantage of this method. Further economic information can be added to the analysis through the multiplicative or exclusionary factors. For instance, it may be relatively easier to grow saplings in particular soil types, producing varying degrees of maintenance necessary to keep the plots healthy. Using a multiplicative factor, the soil types in the study region can be ranked based on their ability to independently sustain the saplings so that sites are selected at least partially on the cost of maintenance after planting. Similarly, perhaps it costs twice as much to reforest areas on a slope greater than 10%. When evaluating sites for selection that have a similar prioritization index value, sites with a slope exceeding this limit can be removed using an exclusionary factor due to their detriment to the project budget. A very real situation where such economic weights are necessary is when land must first be purchased before it can be restored. According to The Nature Conservancy, in the case study we were to assume that all lands within the study area were currently available for reforestation. In other situations, it is far more likely that these lands must be acquired from a public or private source. The market price per acre of these lands can be incorporated as a multiplicative factor for proper management of the project budget. It is once again important to note that these multiplicative and exclusionary indices should remain secondary in the analysis to the convolution index; the decrease of importance on the spatial characteristic of the landscape reduces the disproportional improvement of interior area.

A final economic advantage of the AutoPASS method is that the automation eliminates the need for time-consuming visual interpretation by an expert. While the selecting of sites that meet particular criteria over multiple iterations at first seems complicated, this process can be easily automated through the ArcGIS Model Builder or scripted through ArcObjects. For automation, the user must first prepare the input raster grids(original patch distribution, multiplicative factors, exclusionary factors, etc.), a process the visual interpreter must do anyway, although perhaps in vector format. Upon completion, the user must enter only a few parameters (critical value, maximum amount of area, etc.). The time saved by this automation reduces labor time and prevents the project from becoming delayed by bureaucratic discussion. Further, the automated metric facilitates regional coordination, as the resulting prioritization index numbers hold equal significance across all locations within a region.

It is these economic advantages that make the method practical in other conservation applications as well. Our case study specifically dealt with the ecological restoration of a fragmented forest, but it can be extended to other habitat types. The ecological restoration of grasslands, savannas, and wetlands can be treated similarly under this approach. Instead of assuming a habitat-dominated view, the method can be utilized solely for a specific species. Many species, especially top predators, can often roam across several different land cover types, making land cover delineation less important. In this format, the known range of particular species would be the base grid for analysis, instead of a particular land cover type. The multiplicative and exclusionary factors would then concentrate on that particular species, instead of on the general habitat. The convolution would still produce an array of recommended sites, with reintroduction of the species on these sites paralleling the ecological restoration of a particular habitat. The spatial characteristics of the existing population are thus used to analyze where reintroduction is necessary to both bolster existing populations and provide corridors for migration or intermixing. The prioritization index can also be used to discover which areas in the landscape need to be modified to accommodate the species at hand.

B. Limitations and future directions

The Baraboo Hills case study provides the first real-world application of the AutoPASS method. However, this paper still provides only an exploratory look of the method. The followings are two identified topics to be considered in future research that are important for refinement of the method.

(i) Scale

Scale has been considered a paramount issue in restoration ecology, remote sensing, and GIS since the inception of each field (Southworth et al., 2006). While some have argued that there is perhaps an optimal scale at which to analyze an attribute (Wu and David, 2002), analysis at multiple scales has been given increasing importance (Riitters et al., 1997; Southworth et al., 2006). When quantitatively evaluating shape using the compactness ratio, scale is especially important as coarser resolutions will smooth much of the complexity that minimizes the compactness ratio. In application of the AutoPASS method, scale is synonymous with the pixel resolution of the forest patch grid. Taking a pragmatic perspective, it is advised that the pixel resolution should be equal to the minimum restoration unit to better match the restoration effort. In this way, AutoPASS ties scale to the requirements of the application. However, because the AutoPASS approach is limited to only a single case study, we are uncertain how changing scale will affect the sites locations suggested for restoration. For future studies should examine how well the method holds up across multiple pixel resolutions and levels of fragmentation.

(ii) Heterogeneity of forest patches and weightings

One significant assumption built into the Baraboo Hills case study is the assumption of homogeneity within forest patches. We worked with this assumption for simplicity of setting up the case study because we did not have the domain expertise to factor in habitat quality. It must be acknowledged, however, that habitat compositions are always heterogeneous to some degree (Wu et al., 2000). A central strength of the AutoPASS method is that as long as these variations in habitat quality can be quantified, they can be incorporated into the prioritization. While this provides great flexibility, the quantification of the heterogeneity into a set of weights also allows a degree of subjectivity be incorporated into the analysis. There has yet to be any attempt to match scientifically proven characteristics of a particular domain to a set of standardized AutoPASS weightings, making the assignment of these rankings (and therefore the threshold level) somewhat arbitrary. Sensitivity analysis of the method to weight allocation (ranking) may provide insight for the generation of such a pairing.

VI. CONCLUSION

The proposed method (referred to as AutoPASS) provides a way to reduce fragmentation while increasing interior area using GIS and convolution based on the spatial characteristics of habitat patches. The use of convolution prioritizes potential ecological restoration sites by their effectiveness in both decreasing the fragmentation and increasing the interior area of the adjacent patch. Further, the AutoPASS method allows the incorporation of domain specific knowledge into the prioritization metric.

A case study in the Baraboo Hills of Wisconsin proves that the AutoPASS method is effective in reducing forest fragmentation while maximizing the increase of relative interior area for a given patch. For this case study, the compactness ratio for the entire spatial extent was improved from 0.08989 to

0.11269, a 25% increase. The suggested ecological restoration of 950 acres of forest results in the creation of 2 227 acres of new forest interior, a 235% return.

This automated process avoids labor-intensive and time-consuming visual interpretation for selecting ecological restoration sites. This automation also removes much of the subjectivity of the qualitative visual interpretation method. However, the method still remains flexible by allowing the incorporation of domain knowledge. Using the AutoPASS method, optimal lands can be selected to maximize spatial, ecological, and economic criteria.

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