Reserve Site Selection at a Non-Profit Educational Nature Center

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We investigated a complex planning problem often faced by managers of nature centers or non-profit organizations focused on conservation and public education: how to select sites on which to locate new habitat reserves. Mission statements of these organizations often indicate objectives of both habitat preservation and public education. Inherent in land preservation is limited access to reduce the impacts of human traffic through the area. In contrast, for visitors to fully experience an ecosystem, some access to the site is required, hence seemingly parallel objectives may actually be in conflict. In order to address this problem, we formulated the Educational Nature Reserve Model, combining optimization modeling and geographic information systems (GIS) for generating, visualizing, and evaluating alternative solutions. This model fits situations where conflicting goals of conservation and education must be considered when determining the best location for a new habitat. As a case study, the Kalamazoo Nature Center's main property in Kalamazoo County, Michigan, USA, was examined for the best location on which to reconstruct a native tallgrass prairie. The Educational Nature Reserve Model proved beneficial in the site selection process at the Kalamazoo Nature Center, quickly generating many alternative solutions and allowing trade-offs of objectives among decision makers.

Keywords: GIS, nature center, optimization modeling, prairie reconstruction, reserve site selection, tallgrass prairie.

Nature centers, organizations existing for the dual purposes of habitat preservation and public education, face complex location-planning problems when selecting sites for preservation or restoration projects. The mission statements of these organizations often list education of the public as a primary basis for their existence; ecosystem preservation or representation is a complementary objective of these institutions. Accordingly, when a nature center selects sites for new preserves, it must strike a balance between a location remote enough to sufficiently eliminate continual disturbance, and a site near enough to main paths that interested visitors may visit and fully experience the ecosystem.

As with many planning problems, this site selection problem has no "right" answer. Such planning problems are often addressed by a group of decision makers, each with separate agendas. The needs and desires of these individuals or departments, typically varied and sometimes conflicting with one another, comprise a complex problem to which no simple solution exists. Satisfactory solutions come in the form of feasible compromises. The best solutions provide compromises which accurately reflect the objectives of all of the decision makers involved.

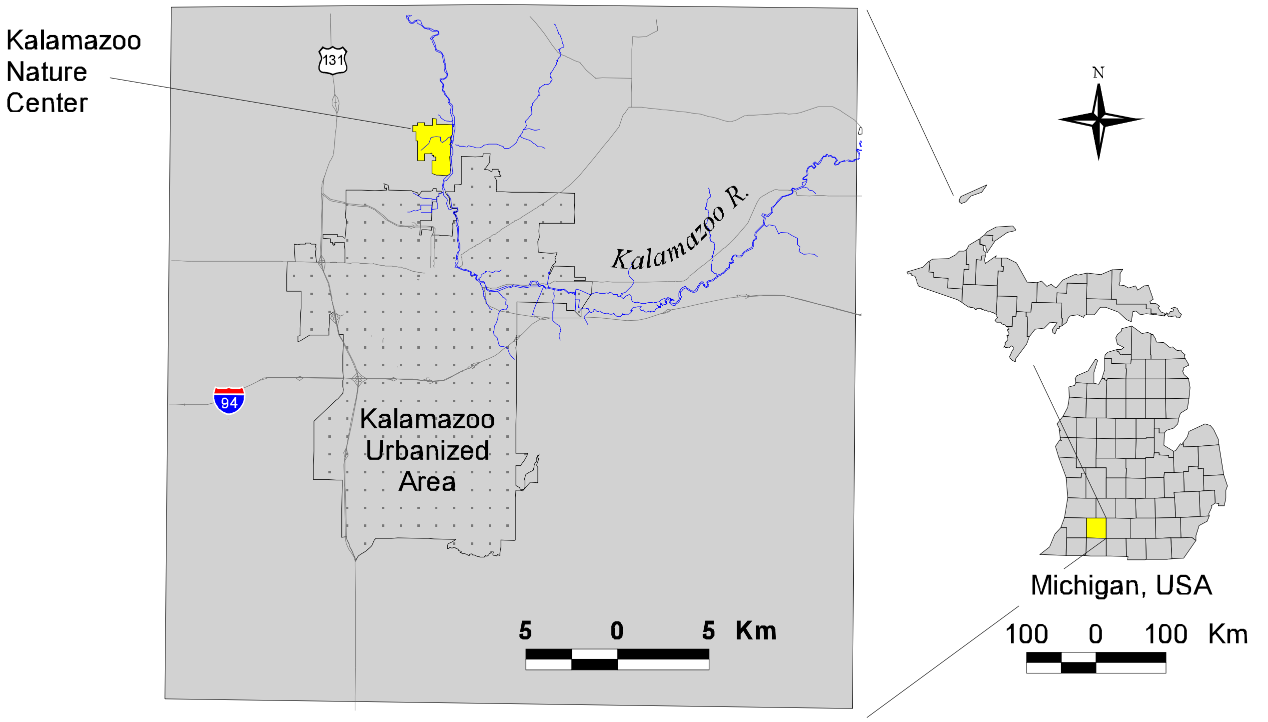

Figure 1: Location of Enviromental Facility in Kalamazoo County, Micigan

One useful method for locating planned preserves is optimization modeling. Combined with a geographic information systems (GIS), this decision support technique facilitates alternatives generation, alternatives evaluation, and alternatives visualization (Jankowski and Richard 1994). Using various scoring and weighting schemes, objectives and constraints can be tailored to generate alternatives emphasizing the different needs of the decision makers. Decision makers can then balance the various needs of the organization as a whole, creating more feasible compromise solutions. This process may be repeated until the group is satisfied with the most agreeable alternative. Key features of this technique are model flexibility and ease of solution generation.

In this paper, optimization modeling, combined with GIS, is used to generate several feasible scenarios for a tallgrass prairie reconstruction at the Kalamazoo Nature Center, an environmental educational facility located in Kalamazoo County, Michigan, USA (Figure 1). The prairie site selection is a difficult problem, addressing conflicting objectives of education, needing easy access by groups, and preservation, requiring limited disturbance by humans. As demonstrated through several solutions explained below, this model can be modified to represent diverse priorities. The Education Nature Reserve Model can also easily be altered to reflect the varying mission objectives of different organizations.

Optimization Modeling

Optimization models (also called mathematical programs) represent problem choices as decision variables and seek values that maximize or minimize objective functions of the decision variables subject to constraints on variable values expressing the limits on decision choices (Rardin 1998). Mathematical programming has been employed by geographers and planners for decades (e.g., Garrison 1959, Ackoff 1962, Greenberg 1978, Killen 1983). Essentially, the objectives and constraints of a problem are quantified. The sum of these objectives are then either minimized or maximized to determine the optimal solution limited by parameters in the set of constraints. Integer programming limits the values of the decision variables to 0 or 1 to force the selection of whole units rather than partial units. Integer programming is usually used in location-allocation problems such as reserve selection because parcels must be allocated in their entirety. Multi-objective integer programming allows multiple objectives in the model that can be weighted to reflect the relative importance of each objective to the solution as a whole. These weights can be adjusted to represent the differing objectives of various decision makers to generate diverse optimal solutions. These methods allow for great flexibility and quick generation of many feasible solutions.

Mathematical programming methods have been applied to reserve selection problems successfully over the past decade, focusing on a wide variety of criteria. Saetersdal et al. (1993) and Underhill (1994) both focused on species diversity; both Camm et al. (1996) and Stoms et al. (1999) addressed habitat diversity. One model presented in Church et al. (1996) maximized species number. Cocks and Baird (1989) devised a model to work around the political constraints of reserve location. Bedward et al. (1992), in an iterative procedure, addressed a problem common to many existing models by minimizing fragmentation in the sites selected. The interactive model developed in their paper allowed users to alter the selection criteria as solutions were generated. Mazzotti and Morgenstern (1997) addressed the next step in the process, the management of natural areas once selection and acquisition has occurred.

However, the models developed thus far have centered on areas where site accessibility by the public is unnecessary or even undesirable. Yet, in the case of the Kalamazoo Nature Center, and other nature centers where education is a prime tenet of the mission statement, accessibility is also key. No models yet exist in the literature which incorporate these two conflicting objectives.

The Educational Nature Reserve Model

The Educational Nature Reserve Model is a procedure which uses the suitability of a site for a restoration project to determine the best locale on which to restore a habitat type. In addition, the conflicting objectives of accessibility and inaccessibility are incorporated. The model aims to choose the most suitable site while maintaining the appropriate balance between the distance objectives. This model builds upon those existing in the literature by incorporating distance objectives to address educational access.

The following is a generalized model formulation for the problem of selecting a site for habitat restoration or planting at an educational nature center.

$$\text{Maximize } Z = \sum_i (w_1 s_i + w_2 r_i) a_i x_i - \sum_i w_3 d_i x_i$$

Maximize the sum of the weighted suitability scores ($w_1 s_i$) and the weighted relative inaccessibility ($w_2 r_i$) of the area of polygons assigned to the reserve while minimizing the sum of the weighted network distance ($w_3 d_i$) to the assigned polygons from selected departure point(s).

Subject to:

1) $\sum_i a_i x_i \le b$ for each i

The area of the assigned polygons will not exceed a size limit.

2) $x_j + \sum_{i \in N_j} x_i \le 1$ for each j

Overlapping polygons and aggregates (groups of adjacent polygons to be assigned as one) cannot be simultaneously assigned to the reserve.

3) $x_i = 0, 1$ for each i

The assignment of site or aggregate i to the system is a binary assignment. No polygons will be split.

Where:

i = index of candidate reserve sites

x_i = decision variable for selection of polygon or aggregate polygon i into the reserve system (1 if site is selected, 0 if site is not selected)

w_1 = weight placed on Suitability Scores

w_2 = weight placed on Distance Ratio

w_3 = weight placed on Network Distance

s_i = composite suitability score of polygon i

a_i = area of polygon i

d_i = Network Distance of polygon i to the closest departure point

r_i = Ratio of area outside of buffer of access in polygon i to area within buffer of access in polygon i

b = maximum total area of sites selected for the reserve

j = index of aggregate reserve sites

N_j = set of polygons that are members of or overlap x_j

Models were solved outside of the GIS environment using CPLEX 6.0 solver on a Pentium personal computer. Decision variables chosen in each solution were viewed in the GIS. This "loose-coupling" allowed models to easily be edited and for many solutions to be generated in a short period of time.

Potential reserve sites, represented as polygons, were defined by natural characteristics. Discrete land units were created by intersecting land cover type, soils, and wetland areas. Polygon coverages were used in this study because they better represented the study sites than grid coverages could at the scale of the study. Areal and distance measurements made using polygon coverages are true distances, and problems such as the Modified Areal Unit Problem (Openshaw and Taylor 1979) are eliminated with the use of polygon data.

An alternative method of defining sites could be accomplished within a raster environment. Using grid coverages to represent natural characteristics of interest, adjacent grid cells with similar values could be aggregated to create potential sites.

Suitability

A measure of a site's appropriateness for a restoration project is represented in the Suitability Score (s_i). Many different characteristics can be incorporated into this measure. The Suitability Score, in the KNC prairie example, is a weighted combination of the soil type, soil moisture content, and land cover at a site. To generate this metric, polygons were first assigned a land cover score ranging from 1 to 5 based on the ease with which they could be planted as prairie. Sites were assigned a soil score of 0, 1, or 5, based on their texture. Gravel pits were assigned 0, wetland soils were assigned 1, and the most well-drained loamy soils were assigned 5. Other soil types were not present on the KNC property. Next, polygons were assigned a soil moisture category based on data collected in the field. The score assigned to the soil moisture type varied by model and was driven by the type of prairie (wet, mesic, dry sand) desired. Land cover scores were then normalized by converting the values to a scale of 1 to 100. Finally, these three terms were each assigned a weight ranging from 1 to 5 based on their relative importance in a particular model run.

The scores were multiplied by their weights and these terms were summed to generate the Suitability Score. In some model runs, a measure of a site's diversity, defined as how many different prairie types could be represented within the plot, was also incorporated into the Suitability Score through the inclusion of another weighted score. In the Educational Nature Reserve Model, the Suitability Score is maximized, making the most suitable sites seem most attractive.

Though simple weights and scores were used to generate the Suitability Score in this example, several other methods could be used to quantitatively arrive at a measure of a site's "appropriateness." If several stakeholders wished to be involved in the assignment of this metric, voting, consensus or the Analytic Hierarchy Process (Saaty 1980) could be employed.

Distance Objectives

The accessibility as well as the inaccessibility of each plot are very important factors to decision makers at a nature center. Efficiently and effectively incorporating these measures into a site-selection problem is the essence of the Educational Nature Reserve Model. Two distance objectives are included in the model to address these conflicting needs.

Accessibility

Visitors to a nature center must be able to approach and enter the different ecosystems represented in order to gain a true appreciation of them. In order to measure the accessibility of the various polygons being considered for the prairie planting, Network Distances (d_i) were measured. In the case of the KNC, the distance from the nearest edge of each polygon to the KNC main building using the existing road and trail network was determined using the "Find Shortest Route" function in the Network Analyst Extension of ESRI's ArcView 3.1. Extensions of the existing network were added to connect polygons not on the network. This Network Distance for each polygon represented the distance a visitor would be required to walk from the main Nature Center building in order to reach the prairie. All distances were normalized to a scale of 1 to 100, where the shortest distance was set equivalent to 1, the longest distance was set equivalent to 100, and distances between were assigned the appropriate normalized value. Because the landscape of the Kalamazoo Nature Center is rolling hills and flat plains, this representation of the road and trail network assumes that equivalent distances walked on roads and trails are covered in the same amount of time. However, in situations where trails are substantially more difficult, an impedance factor could be coded into the trail arcs. This term is minimized in the Nature Reserve Model.

In successive runs of the model, satellite parking areas were included as access points. These were areas where small parking areas or turn-offs could be appropriate. With multiple access points, each polygon's distance was recalculated to the distance to the closest access point. The inclusion of such additional access points has the potential to have a large impact on the accessibility of certain portions of a reserve, as was observed in the solutions generated incorporating the satellite parking areas.

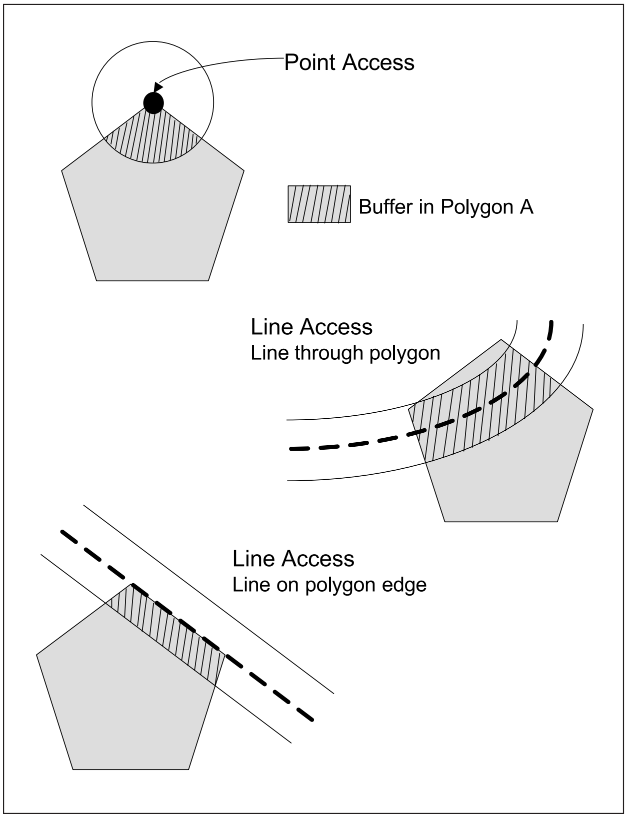

Figure 2: Methods for calculating the inaccessability (r_i) of a plot within the ENRP model

Inaccessibility

It is well understood that sites recently planted, including tallgrass prairies, benefit from minimized traffic (Forman 1995; Kline 1997). Trampling of young plants, soil compaction, introduction of exotic species, and prairie seed theft are all concerns at restoration sites. Employees at the Kalamazoo Nature Center recognize these impacts, and consequently, wish to see at least a portion of the planned prairie planting remain inaccessible to visitors. Minimized traffic would also benefit fauna attempting to inhabit the site.

A measure was developed to represent the inaccessibility of a plot. A buffer can be generated for some distance to be set as the accessibility distance. If there is no linear trail feature within or alongside the polygon, the buffer is calculated from the polygon's access point. If there is a trail attached to the polygon, the buffer is calculated from the line segment intersecting the polygon (Figure 2). Inaccessibility distances were normalized to values from 1 to 100, similar to accessibility distances.

A ratio (r_i) was created where the area of the polygon minus the area of the buffer within the polygon was divided by the area of the buffer within the polygon. This results in a ratio of inaccessible reserve to accessible reserve. In this measure of inaccessibility, larger polygons, polygons located off the main trails, and those with centers of gravity offset from the trail have a greater ratio. Maximizing this term in the Educational Nature Reserve Model favored polygons possessing greater areas of less accessible space.

Size Limit

An upper bound was placed on the amount of area which could be assigned as the habitat reserve. This ensures that the model does not assign the entire property under consideration as the habitat reserve. Because this model maximizes the objective function, it adds sites continually in order to obtain the largest objective value possible. If not restricted, the model would continue to add sites until the entire property was assigned. By placing an upper bound on the area to be assigned, the model is forced to search for the combination of sites which results in the largest objective value while remaining within a given size limit.

In order to minimize fragmentation in solutions, aggregates of adjacent polygons were created. Aggregates of various sizes were generated, ranging in area from approximately ten acres to up to 40 acres. Aggregates were comprised of several adjacent polygons of similar site characteristics. A constraint was included for each aggregate which allowed the model to either select the individual polygons, or to select the aggregate, but not both. Overlapping aggregates also could not be selected.

Solution Alternatives

The Kalamazoo Nature Center, a facility with over 1000 acres situated in a nearly rectangular block, has for several years struggled with selecting an optimal location at which to site a tallgrass prairie reconstruction. This organization, which aims to "inspire people to care for the environment by providing experiences that lead them to understand their connection to the natural world" (Welcome to the Kalamazoo Nature Center 2002) faces a difficult site selection task for this project. The Educational Nature Reserve Model offers a technique for successfully balancing the varying components of such a problem. Below are several solutions generated for the proposed prairie reconstruction at the Kalamazoo Nature Center, each placing emphasis on a different set of objectives from each decision maker. Though no solution was found which met all of the desires of the Nature Center decision makers, using optimization modeling to represent these needs numerically allowed several feasible alternatives to be generated quickly for further consideration.

Stewardship

Stewardship departments at nature centers typically focus on managing property based on the desires set forth by the organization. "Wise use," a term commonly used to describe the management of lands to benefit humans as well as the members of the ecosystem (Scheffer 1989), is an underlying principle for stewardship departments at environmental education centers. The Stewardship Department at the Kalamazoo Nature Center aims to operate within such guidelines, and as a result, maintains a set of requirements it would like to have met for the planned prairie reconstruction project.

The planting and maintenance of this community would primarily be performed by the Stewardship Department. Therefore, these employees are interested that the prairie be accessible by not only foot traffic, but also by maintenance vehicles such as mowers and fire trucks. The Director of Stewardship at the Kalamazoo Nature Center also expressed interest in a total of at least 40 acres of prairie plants, with a plot measuring at least 10 acres located within close proximity of the main KNC building for the purpose of enjoyment by the visitors. Finally, the Director of Stewardship requested that an easily accessible site for seed production be considered.

Solution

A solution to the Stewardship model is depicted in Figure 3. In this run, the Network Distance was given a weight of 5 in order to encourage clusters of polygons located within a short walking distance of the KNC main building to be selected. Suitability and Accessibility were given smaller weights, each a 1, as these terms were less important to the stewardship department. The maximum area allowed for this solution was 55 acres.

In this alternative, two aggregates and one additional polygon were chosen, A, B, and Polygon 99, with sizes of 9.5 acres, 31.6 acres, and 13.9 acres, respectively. This solution is viable because it meets all of the stewardship requirements and the polygons chosen are clustered, rather than scattered about the KNC property. All plots were within 0.7 of a mile of the main building via the existing trail network, meeting the requirement that at least 10 acres be within a short walking distance. Aggregate A, a cluster of polygons adjacent to the existing prairie, comprised nearly 10 acres. In addition, an existing trail passed along the southern and eastern borders of this cluster, allowing visitors to walk entirely through the planting and experience it intimately.

This solution also meets the accessibility requirement for maintenance purposes. All plots were adjacent to existing roads or vehicle-accessible trails. This solution allocated approximately 55 acres as prairie, surpassing the requirement of at least 40 acres. Though no separate plot was chosen for the express purpose of seed production, this activity could easily be relegated to one portion of the selected sites.

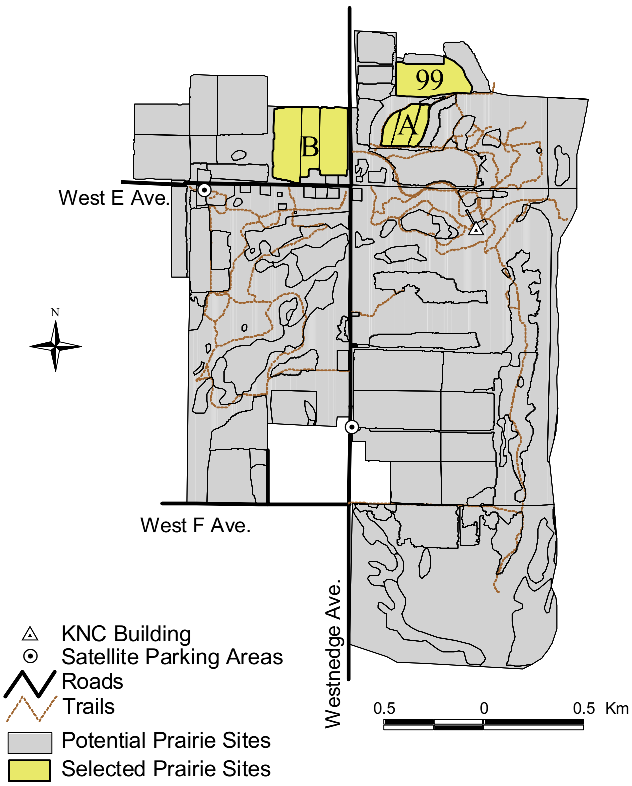

Figure 3: Solution to Stewardship model

Research

The founders of the Kalamazoo Nature Center recognized the importance of ecological research, believing it to be the cornerstone of education and conservation (Kivikko et al. 1995). This opinion is shared by many other environmental education facilities across the United States (Aldo Leopold Nature Center 1998; Konza Prairie Research Natural Area 1999; Friends of the Prairie Learning Center 1999; Wehr Nature Center 1999). With an emphasis on avian research, KNC is particularly interested in the fauna which could be restored to a prairie habitat. The members of the Research Department foresee the opportunity to maintain a patch of native Michigan prairie large enough to host populations of locally rare fauna including Michigan's waning grassland birds, several of which are state listed.

Minimum patch size is the main limiting factor for birds, mammals, and reptiles which might inhabit a prairie. The minimum patch size necessary for the insect-feeding birds in which the Research Department employees expressed interest has been established to be approximately 100 acres (Forman et al. 1976; Galli et al. 1976; Sample and Mossman 1997; Smith 1997). This patch must be compact in shape and experience little disturbance. Members of the Research Department also desire representations of different types of Michigan prairie such as dry sand or wet mesic, given that this could be accomplished within a large, contiguous block of prime grassland bird habitat. The site diversity measure was incorporated into the suitability scores used in the Research model.

Solution

One solution generated using the Research Department's preferences is presented in Figure 4. In this model run, Suitability was given a weight of 1, Accessibility a weight of 2, Inaccessibility a weight of 3, and maximum area 100 acres. This solution provides a compact, diverse, and largely inaccessible plot totaling

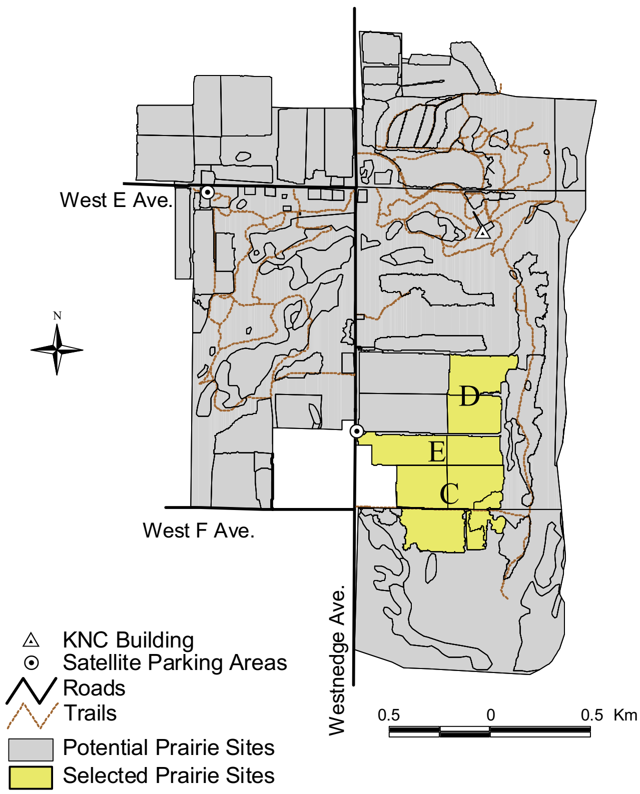

Figure 4: Solution to Research model

99.3 acres. The closest portion of this plot is a 0.75 mile hike along difficult terrain from the main KNC building, which would discourage many visitors from entering the site from the east. However, Westnedge Avenue, a main county road, passes along the western edge of this plot. Visitors could use this opportunity for viewing the planting. In addition, this road provides easy access for maintenance vehicles. An existing maintenance trail also passes through the middle of this cluster of plots, offering additional opportunities for prairie maintenance and visitor access, if desired.

This combination of aggregates also meets the Research Department's desire to demonstrate sites suitable for a variety of prairie types. The southern portion (aggregate C) demonstrates conditions appropriate for all five prairie types. The eastern portion of this site provides the proper environment for dry sand prairie plants; moisture slowly increases to the west. Soil moisture content is high enough in the south and west portions of this aggregate to support wet prairie plants. To the immediate southwest of this aggregate is a seasonally flooded emergent palustrine environment (U.S. Fish and Wildlife Service 1981), demonstrating this moisture availability. The other two aggregates chosen in this solution, D and E, both provide suitable conditions for mesic and dry mesic prairie types.

Education

Sharing an appreciation for nature and fostering a sense of stewardship for the earth is the most prominent goal in the Kalamazoo Nature Center's mission statement, as with most other environmental education facilities in the United States. Nature centers' education and outreach employees experience the most contact with visitors and work to make the mission statement a reality. The proposed prairie planting at the Kalamazoo Nature Center would provide visitors the chance to experience an ecosystem which has all but disappeared from southwest Michigan's landscape. As such, educators at KNC emphasized the value in offering a wide variety of prairie types for visitors to experience. Also, because Nature Center employees wish to expose as many visitors to the planned prairie as possible, it was decided that at least a portion of the total acreage be located within a 0.5 mile distance of the main KNC building. Though educators at KNC did not require a specific acreage to be met, a minimum of 40 acres was chosen.

Solution

Figure 5 shows a solution generated using the KNC educators' preferences. In this run of the model, Suitability was given a weight of 4, Accessibility a weight of 3, Inaccessibility a weight of 1, and maximum area 80 acres. The result is a more fragmented solution demonstrating a wider range of moisture and soil conditions. Polygons 12 and 19, 0.48 acres and 0.93 acres respectively, are both wetlands classified as palustrine by the U.S. Fish and Wildlife Service (1981) and offer the opportunity to represent plots of prairie fen and wet prairie. Polygon 12, the plot exhibiting conditions appropriate for a prairie fen, is in direct view of the Nature Center's main building and is easily accessible via a 500 foot walk.

The other sites chosen in this solution, aggregate F and Polygon 119, constitute a large, compact plot of 78.4 acres. This

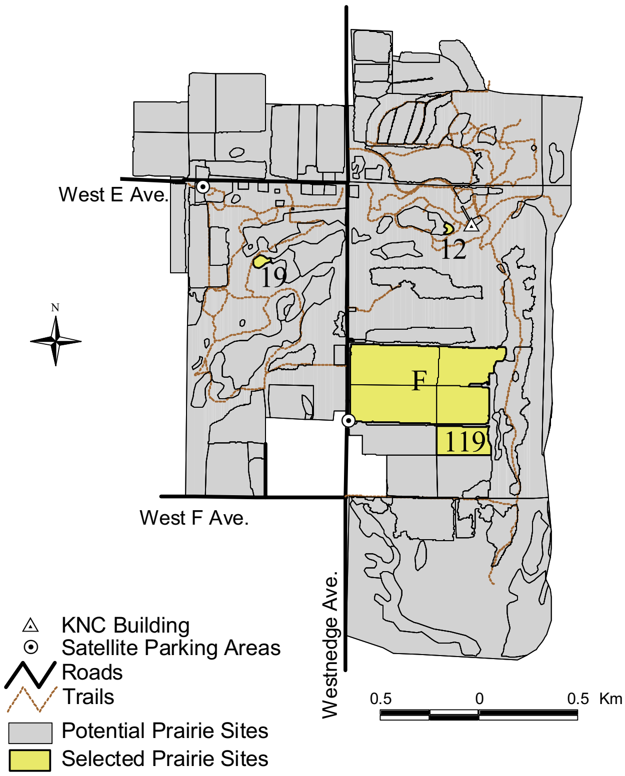

Figure 5: Solution to Educational model

area exhibits conditions suitable for primarily mesic plants. Drier conditions exist on the eastern portion of this cluster, appropriate for a dry mesic prairie representation. This cluster is a 0.75 mile walk from the main KNC building via existing trails, which decreases the number of visitors which might be able to experience the site but enhances the habitat for wildlife. However, the plot is bounded on the west side by Westnedge Avenue, and offers easy access to maintenance vehicles as well as a splendid view to visitors traveling along this road.

The one requirement that this solution fails to meet is that no representative prairie exists within a 0.5 mile hike or less from the main building. As a tradeoff for a sizable prairie cluster located close to the KNC main building, this solution offers a great diversity of prairie types. The model's weights could be altered to generate other solutions which balance these needs more suitably.

Director

As with many other nature centers nationwide, the Kalamazoo Nature Center exists for the purposes of preserving a corner of the environment and educating the public about its value. Individual departments of such an organization carry out various aspects of this mission; different units may emphasize one portion of the mission more than another. The job of a director of such an organization is to maintain the appropriate balance between the various departments in order to successfully accomplish all of the organization's goals while still operating within the given budget.

As a result, the Director's desires for the planned prairie reconstruction at the Kalamazoo Nature Center represent a balance between the preferences of the Stewardship, Research, and Education departments. The proposed prairie must exhibit a balance between accessibility, for the purpose of education, and inaccessibility, for the purpose of restoration and preservation. It must also be accessible to maintenance vehicles. It must be large enough to provide an accurate representation of southwest Michigan's presettlement prairies, but be small enough to be affordable and manageable. The key descriptive term for such a plot is "balance."

Working to achieve this balance, the Director of the KNC requested that the prairie occupy close to 100 acres, recognizing the benefits of a sizeable plot. The director's preference was that this planting be primarily mesic prairie, acknowledging that prairie plots of this type and site were most common to southwest Michigan prior to settlement. However, he also recognized the value in representing various prairie types now rare in this portion of the U.S., and requested that if a plot could be located in which a continuum of several prairie types could exist, that this site be recommended.

Solution

Figure 6 shows a solution generated which balances the needs of the various KNC departments. In order to balance accessibility with inaccessibility, both the Network Distance and the Ratio Distance terms were given a weight of 3, Suitability was given a weight of 1 and maximum area was set at 100 acres.

This solution meets the requirements of the Director Model well. Aggregates G and H, which constitute a compact block in the southern half of the property, demonstrate conditions appropriate for prairie types ranging from wet to dry sand.

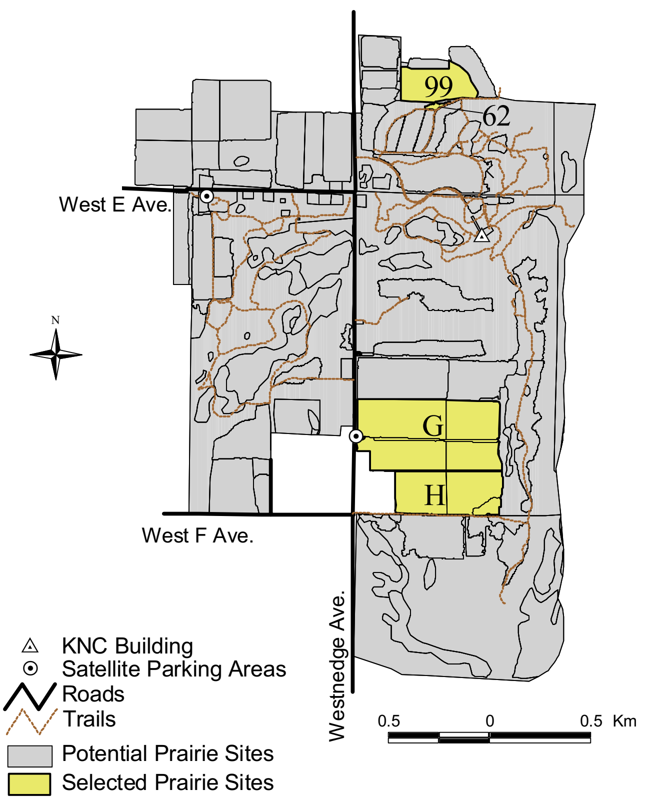

Figure 6: Solution to Director's model

Table 1. Comparison of four solutions generated for the Kalamazoo Nature Center planned prairie reconstruction.

	Weights & Parameters (Suitability, Accessibility, Inaccessibility, Area Limit)	Polygons Chosen	Total Acreage	Distance to KNC Building	Notes
Stewardship Solution	1, 5, 1, 55 acres	A, B, 99	54.19	All three plots within 0.70 mile	All plots adjacent to roads or vehicle-accessible trails
Research Solution	1, 2, 3, 100 acres	C, D, E	99.30	Closest portion 0.75 mile along difficult terrain	Excellent view from road;moisture continuum exists in large plot
Education Solution	4, 3, 1, 80 acres	F, 12, 19, 119	78.40	Polygon 12, within 500'; large cluster 0.75 mile walk	Great diversity of prairie types
Director Solution	1, 3, 3, 100 acres	G, H, 62, 99	99.47	Large plot 0.5 mile; handicapped parking available	Northern plot very accessible; southern plot rather remote

Polygons 62 and 99, comprising a tight cluster just over 0.5 mile from the main KNC building, exhibit conditions for mesic prairie. Total acreage for the plots was 99.47 acres. The northern cluster in this solution is highly accessible, bounded on nearly all sides by trails. Parking is available at the main parking lot, located 0.3 mile to the south; handicapped parking spaces are located 200 yards to the east. The southern cluster is also quite accessible, bounded on the west by Westnedge Avenue and on the south by a dirt road.

These two clusters balance accessibility and inaccessibility well. The northern site, with its close proximity to the main KNC building and parking lot, offers a great deal of opportunity for visitors of all ages and ability levels to intimately experience the prairie. Trails could be constructed into or possibly through the plot, allowing sightseers to be surrounded by grasses and flowers. Conversely, the southern plot is a much greater distance from the main building. Though Westnedge Avenue bounds this plot on the west, no parking is available. A two-track runs east along the southern end of this cluster, but is currently not open to the public. These factors would discourage visitors from traveling to this site, keeping traffic to a minimum. Minimal disturbance would allow a more well developed prairie ecosystem to emerge. Additionally, the plot is nearly square in shape, minimizing the amount of perimeter, and therefore edge effects.

Conclusions

The benefits of using optimization modeling for site selection include flexibility of problem formulation as well as ease of solution generation. Using this technology, many different scenarios can quickly be formulated and visualized for further consideration. The Educational Nature Reserve Model is designed to allow educational nature centers to generate alternatives to problems that balance their conflicting objectives of public education and land preservation. The solutions presented for the Kalamazoo Nature Center planned prairie planting demonstrate how the model can be changed to fit different sets of needs. Table 1 summarizes the solutions presented above.

The Educational Nature Reserve Model is a product which can be applied to a wide variety of site selection problems. The rather generic objective terms of the model allow for application to any sort of reserve location problem, regardless of the type of habitat. The objective function balances measures of suitability, accessibility, and inaccessibility. The general term of suitability possesses great flexibility; this term incorporates the physical characteristics of a site which pertain to the reserve in question. The innovation of this model lies in the conflicting terms of accessibility and inaccessibility. Contrasting visitor accessibility versus habitat protection in addition to site suitability allows quality reserve sites to be selected for the spatially limited activities required for environmental education and habitat preservation. Additionally, because the model can use either vector or raster data and discrete or aggregate polygons, sites of any scale can be considered. Future extensions of this model could incorporate additional site characteristics. Measures of patch suitability such as compactness and amount of edge could be incorporated into the site suitability metric. Habitat attributes such as fragmentation of solutions could also be added into the model.

In order to fully understand and accurately represent the various Kalamazoo Nature Center departments' needs, the researcher interviewed representatives of each department. This helped the researcher to better understand each of the decision makers' specific desires for the planned prairie. A concise list of needs for each of the stakeholders enhanced the modeling process and allowed the various alternatives to be quantitatively compared.

The system employed in this study, which integrated modeling and GIS technologies, is appropriate for problems where several decision makers are involved. Often, decisions such as site selection are accomplished by a group of individuals representing different interest groups. Organizations such as nature centers are faced with this challenge; solutions must balance many different needs and meet several, possibly conflicting, objectives. In situations such as these, the ability to quickly generate and visualize many different solutions greatly enhances the decision-making process. Decision makers are potentially more apt to reach consensus if provided with a set of viable alternatives rather than allowed to suggest any solution. In some cases, multi-criteria decision making is being combined with GIS technology in interfaces known as spatial decision support systems (SDSS) (McClean et al. 1995; Malczewski 1999). Though such an interface was not developed with this model, one could be created in the future.

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