Spatial Optimization and GIS

Locating an Optimal Habitat for Wildlife Reintroduction

By Guido Guerra and John Lewis, McGill University

***Editor's note:** This article illustrates a process for obtaining optimized spatial solutions using programming methods with spatial analysis techniques. To demonstrate this process, a hypothetical problem—siting a reserve for reintroducing a wildlife species—is used. In this example, the preferred habitat for the species was known. A mathematical model was defined, and an external linear programming solver was used to obtain optimal site characteristics. The search for a suitable area was based on land cover maps analyzed using ArcView 3.2 and the programming model. The resulting map rates all sites according to similarity to the optimal site.*

The linear programming and GIS tools available today afford better implementation and integration of spatial data analysis so that optimally suitable sites can be identified, or at least, sites can be rated as to their "closeness" to the optimal solution. A hypothetical problem—reintroducing a wildlife species—was solved based on an optimal location that takes into account spatial as well as financial considerations. After defining the linear mathematical model for the optimization objective and the spatial criteria, a linear programming algorithm was used to solve the problem. The programming solution defined the spatial requirements for the optimal site, which provided an indication of the spatial analysis needed to identify suitable sites. Finally, a simple weighted sum of the differences was used to rate each site according to its similarity to the optimal site.

Defining the Problem

The 25 adult animals that will be released require both edge land (i.e., land on the border between forest and field land) and field land. For the purposes of this example, edge land is defined as a strip of land 10 meters (m) wide. A single animal needs 40 running meters of edge land and 6,000 square meters (m^2) of field land. The example assumes that edge land size is three times more important than the field land size because edge land is used by these animals for protection against predators, reproduction, and foraging.

The projected man-hour resources available for this reserve will not permit the operation of a reserve larger than 150,000 m^2. Also, the cost of the land for the reserve cannot exceed the $200,000 that has been budgeted. In the study area, forest edge land can be bought for $4.50 per m^2. Field land in proximity to edge land costs $0.50 per m^2. The objective is to *maximize* the size of the reserve while keeping the project economically feasible. Land that fulfills these requirements may be purchased for the reserve.

The Mathematical Model

Based on the land cover map, the linear optimization problem is described in Figure 1 and the criteria are shown in Figure 2.

Solving the Linear System

Using an add-in tool that comes with Microsoft Excel, Microsoft Excel Solver, and solving for the optimal edge and field sizes for the reserve yields the results shown in Figure 3.

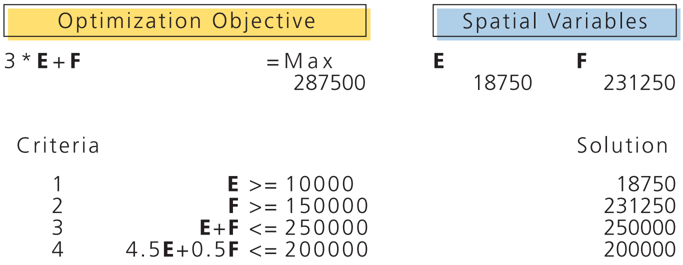
Figure 1: Linear optimization problem

Objective Function=Max(3E+F)
where E=a strip of forest 10 m wide
F=a field adjacent to the edge

Figure 2: Criteria

Criteria	Description
1.	**Edge Size = E (25 adults x 40 m/adults x 10 m = 10,000 m^2)**
2.	**Field Size = F (25 adults x 6,000 m^2/adults = 150,000 m^2)**
3.	**The man-hour resources imply that the, Reserve Size = E + F (250,000 m^2)**
4.	**Cost of Reserve = 4.5E + 0.5F <= $200,000**

Figure 3: Results of linear programming solver



Optimization Objective		Spatial Variables	
3 * **E** + **F**	= Max 287500	**E** 18750	**F** 231250

Criteria		Solution
1	**E** >= 10000	18750
2	**F** >= 150000	231250
3	**E**+**F** <= 250000	250000
4	4.5**E**+0.5**F** <= 200000	200000

The optimal solution is 18,750 m^2 of edge land and 231,250 m^2 of field land adjacent to the edge land. Using ArcView 3.2, sites on the land cover map that most closely conform to these edge and field size requirements were located using the procedures described in the following section. A rating system, based on the sum of differences from the optimal solution as expressed in the formula shown in Figure 4, was calculated for each field within the feasible zone. Figure 5 illustrates the interaction of criteria to determine the feasibility zone.

A rating of zero indicates a perfect match to the optimal solution. Each rating value was multiplied by a factor of 0.0001 to reduce its magnitude. This approach discriminated between oversized and undersized sites by retaining negative rating values for undersized sites.

GIS Integration

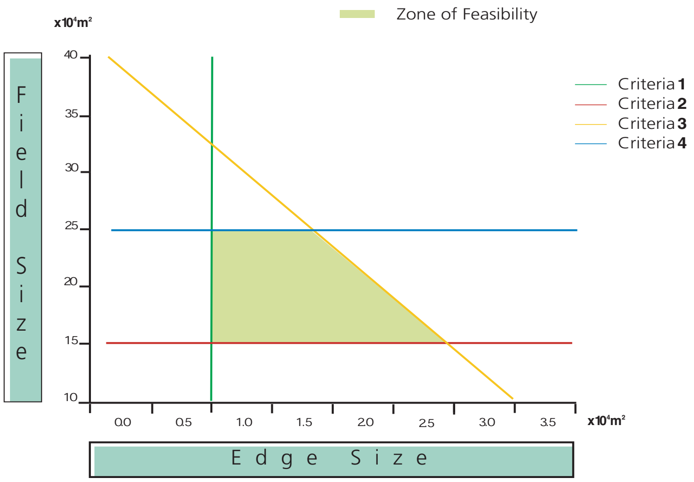
Vector-based data was deemed suitable for the spatial analysis portion of the optimization. Figure 6 summarizes the procedure used. The original data for this analysis was a polygon land cover map of the area of interest in shapefile format. The forest and field classified polygons were extracted and converted to separate shapefiles to reduce both the time required and the complexity of data processing. A polygon theme identifying the forest-edged fields was created by intersecting the dissolved 1 m outer buffer of the forest cover with the dissolved 10 m outer buffer of the field cover. (The 1 m buffer was added to the forest theme so that the Field_ID for the repective edge borders would be retained.)

Figure 4: Rating formula

$$\textbf{Rating} = \sum_i w_i\,(\textit{actual value-optimal value})$$

where:
i over all optimization variables
and
w is the same as the weight used for the objective equation

Figure 5: A rating based on sum of differences from the optimal solution for each field within the feasible zone



Buffer operation can produce “overspills” onto roads, rivers, and areas containing other land cover types. Intersecting two themes can also produce slivers and multiple polygons (i.e., many polygons with the same attributes). In addition to these challenges, the edge theme, obtained by intersecting the forest-edged theme with the forest theme, may create several edge sections bordering the same field. To obtain the total edge size around a given field, the edge polygons were dissolved based on the Field_ID assigned to each polygon. The removal, cleaning up of unwanted polygons, and dissolving of the edge polygons were more arduous processes than expected, and describing these procedures in detail could be the subject of an entirely separate article.

The edge and field areas for each parcel were calculated using View.CalculateFeatureGeometry (calcapl.ave), an Avenue script available from ArcScripts at the ESRI Web site. This script calculates area and perimeter for a polygon theme and length for a line theme. Joining the edge attribute table to the field attribute table using the Field_ID field allowed rating and costs associated with each field to be calculated. A map displaying the most suitable parcels was generated using a four-color scheme based on rating values. All parcels were rated, but parcels that fell outside the minimum requirements for edge and field size were assigned a value of 999.

Figure 7 shows the field attribute table after all calculations were made. Area measurements are given in square meters. Field_ID 24 has a rating of 0, which makes it an almost perfect match—*except* that the criteria for the size of the reserve was exceeded by approximately 4,000 m^2. This process identified other sites that were less than optimal but might provide suitable choices. If cost had been the primary consideration, Field_ID 30 and Field_ID 13 would have made satisfactory choices.

Conclusion

This article illustrates how spatial analysis can be used to identify an optimal location based on spatial criteria such as adjacency, proximity, size, and shape. Optimization requires extensive expert knowledge to

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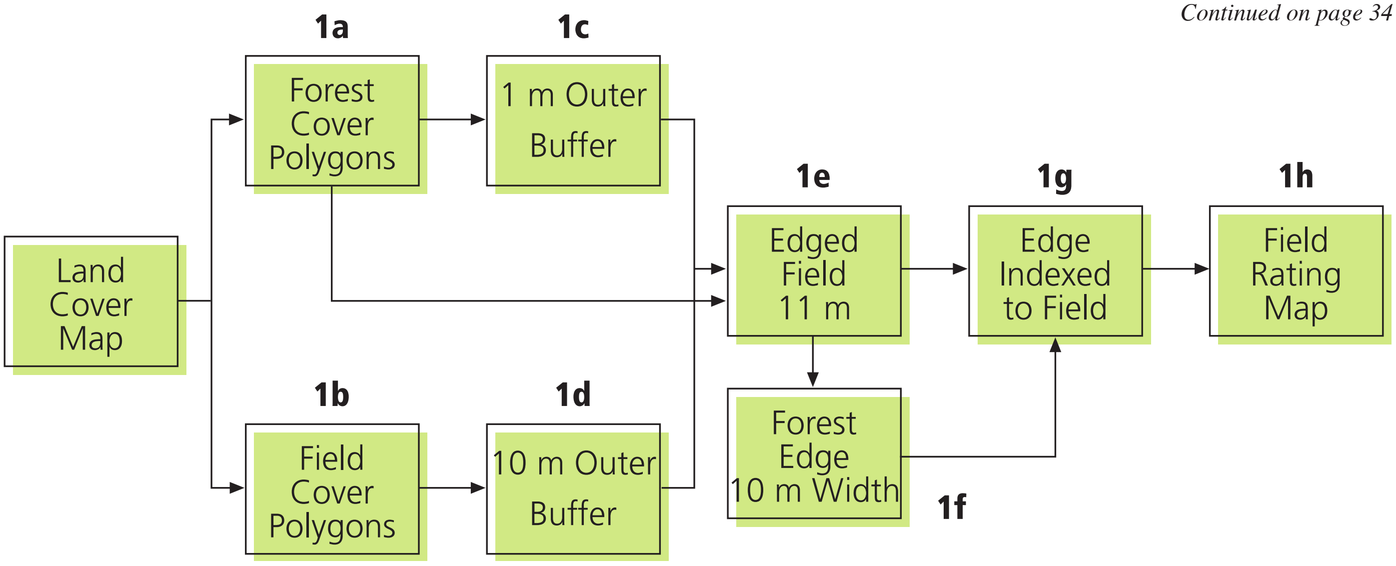
Figure 6: Model Schematics



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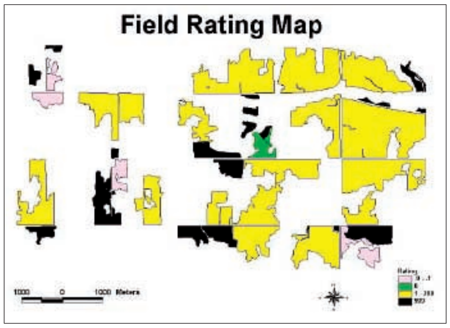
extract the appropriate optimization objective and criteria within a spatial context. Although the example given in this article is rather simple, the approach and procedures could easily be extended to more complex problems where proximity to roads, water, utilities, or other features could be considered in relation to elevation, slope, aspect, and meteorological or demographic criteria to select an optimal location. Optimization modules can be developed for individual scenarios that represent typical kinds of problems. The end user of such an application could change the geographical location (i.e., map extent), the weight constants of the objective function, and the boundary values of the criteria as needed.

In this example, an external linear programming solver, Microsoft Excel Solver, was used without a real discontinuity in the process. However, it is not inconceivable that a linear programming algorithm could be accessed directly from within the GIS application via a menu choice. The integration of linear programming and GIS depends on the ability of the user to clearly define the optimization objective and criteria within a spatial context and convert the solution into map information.

Figure 7: Field data attribute table after calculations

Field_ID	Field_AREA	Edge_AREA	Reserve_AREA	Cost	Rating
8	158533	13935	172468	$141,974.00	-9
42	156626	12418	169044	$134,194.00	-9
2	175628	15846	191474	$159,121.00	-6
13	203572	11843	215415	$155,079.50	-5
30	221001	12116	233117	$165,022.50	-3
24	236362	17630	253992	$197,516.00	0
37	351249	13646	364895	$237,031.50	10
36	348259	19796	368055	$263,211.50	12
15	391056	13139	404195	$254,653.50	14



Four-color map of all the fields that should be considered for purchase. Fields that did not meet the minimum size requirements were given a value of 999.

Although the focus of this article was not wildlife management, the authors welcome any opportunity to apply the process described here to wildlife resource management research or any other field that could benefit from the integration of linear programming and GIS to reach an objective solution.

For more information, contact

John Lewis
Department of Geography
McGill University
Montreal, Quebec, Canada
E-mail: lewis@felix.geog.mcgill.ca
Tel.: 450-671-3201