Planning for Restoration: A Decision Analysis Approach to Prioritization

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Abstract

Ecological restoration often relies on the use of expert opinion to make management decisions in the face of uncertainty. The quantification of expert opinion can be difficult, especially when more than one expert is consulted and experts are not in agreement. Decision analysis can provide a framework to systematically deconstruct a complex problem and provide greater objectivity to restoration decisions. We utilized decision analysis techniques to identify restoration objectives and to quantify expert opinions to prioritize restoration activities at 112 prairie openings in the Edge of Appalachia Preserve in southern Ohio, U.S.A. We first created an objectives hierarchy to model how decision-makers decide which prairies to manage. We then determined how to measure each component of the hierarchy and sampled all prairies for percent woody cover, geology, indicator species index (an index of plant species richness), slope, aspect, and distance to nearest prairie. We modeled seven different experts' preferences for managing prairies with varying values for each of these ecological measures. We then interviewed the same decision-makers to determine relative weights for each component of the objectives hierarchy using trade-off analysis. By combining the weights, preference relationships, and sampling data, we were able to rank each prairie and management unit based on its management priority. Experts had similar preferences except for the measure of distance to nearest prairie. We found that decision-makers gave different weights to each of the different components of the hierarchy. Generally, experts weighted percent woody cover, indicator species index, and geology more highly than slope, aspect, and distance to nearest prairie. Despite these differences, priorities for management, once all factors were weighted and combined, were similar.

Key words: burning, conservation planning, Edge of Appalachia, limestone prairies, multiattribute analysis, Ohio.

Introduction

A primary goal of ecological restoration is to restore ecosystems to a target level of ecological integrity (Wyant et al. 1995; Parrish et al. 2003) or, in other words, to reestablish "pre-disturbance functions and related physical, chemical and biological characteristics" (NRC 1992). Meeting this goal requires analysis of ecological and physical factors that determine limits to the ecological composition, structure, and function of an ecosystem (Wyant et al. 1995). Unfortunately, reference ecosystem conditions and ecological integrity are frequently unknown for restoration projects. Adaptive management provides a way to incorporate information gathered as management proceeds into future management actions, yet can be a lengthy process (Walters & Holling 1990; Haney & Power 1996). To make rapid decisions on restoration management, management experts rely on experiential knowledge of ecological integrity. Often there is some knowledge of how different components (i.e., ecological and physical processes) of ecological integrity interconnect, but the expert opinion used to assess the importance of different ecological integrity components is neither quantifiable nor consistent among different experts.

Management of prairie openings at the Edge of Appalachia Preserve (EOA) in southern Ohio, U.S.A., provides a case study of these complexities in making restoration prioritization decisions. The ecological integrity of prairie openings at EOA is threatened by shrub and woody plant succession. Studies of aerial photographs taken in 1938, 1950, 1965, and 1971 found that EOA prairies are succeeding to forest (Annala & Kapustka 1983; Annala et al. 1983). To control the encroachment of shrubs and woody plants and to reintroduce a necessary disturbance regime, preserve managers have selectively managed these prairies by prescribed burns, hand cutting, or a combination thereof. This management, however, has been complicated by a number of obstacles. There is some lack of consensus in the scientific literature as to the origin, original extent, and components of ecological integrity of the prairie openings. In her early studies of the EOA prairies, Braun (1928) concluded that the prairies in this area were relicts of a more extensive prairie community, and the larger openings represented a climax stage of prairie succession. However, researchers have suggested recently that most of the prairies were anthropogenically

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maintained (Baskin et al. 1994; Anderson et al. 1999; Baskin & Baskin 2000). It is difficult to determine land use histories and determine which prairies are abandoned fields and which are more "primary" prairies. Post-settlement fire interval averaged 3.9 years (White & Huffman, unpublished data); yet, there is no clear scientific evidence of the nature and frequency of the pre-European settlement disturbance regime.

Managers at EOA have developed guidelines directing management intensity and frequency by collecting data after burning and management events; yet, much remains to be learned. There is still a great deal of subjectivity and expert opinion in defining management priorities at this site. Although simple to implement, this method of restoration planning has a few important limitations. It is largely subjective in its consideration of complex, interrelated data because the human mind cannot easily quantitatively assess all the various factors considered in making management decisions. It is fragile in the sense that the knowledge base used to make management decisions can be easily lost with key personnel, and it does not foster a goal-based review of management decisions and associated ecological measurement of success (Parrish et al. 2003).

Further complicating management is the large number of prairies coupled with fiscal and human resource limitations, which make analyzing and managing all the prairie openings a difficult task. As a result, a majority of the prairies have not been routinely managed to date. Prioritizing restoration activities can be difficult when given many possible areas for restoration. Choosing an appropriate site to manage will increase the probability of success and efficiency of restoration (Pieterse et al. 2002). In light of capacity and other management constraints, it is necessary to devise a way to quantify and model expert opinion and decisions within the framework of ecological integrity enhancement. The purpose of this study is to provide restoration managers with an objective, organized, and user-friendly method for prioritizing management.

Decision analysis techniques, developed for business applications, can provide a way to deconstruct complex problems and provide structure to a decision process that leads to better decisions (Clemen 1996). Decision analysis elucidates the complexity involved in decision-making, clearly showing all the components that go into making a particular decision. This approach has been used in relation to resource management issues, such as cost-benefit analysis of fire management (Cohan et al. 1984), endangered species management (Maguire 1986), conflict resolution (Maguire & Boiney 1994), and savanna restoration (Norton & Walker 1985). Decision analysis can also be used to determine research needs (Norton & Walker 1985). It incorporates methods for quantifying subjective expert opinion when scientific data are lacking. We used decision analysis to prioritize management activities on 112 limestone prairies at EOA by capturing and modeling the expert knowledge used to manage the land and combining this knowledge with ecological sampling data.

Study Site

The Richard and Lucile Durrell EOA protects roughly 13,000 acres of predominantly forested land and is managed jointly by the Nature Conservancy and the Cincinnati Museum Center. Located along the Appalachian Escarpment in southeastern Adams County, Ohio, the preserve lies along the border of two of Ohio's physiographic regions, the Western Allegheny Plateau and the Interior Low Plateau (Bailey 1994). The town of Lynx, Ohio (lat 38°46′23′′N, long 83°24′47′′W), is located centrally to the preserve. EOA is home to a diverse array of ecosystems including large forested tracts interspersed with openings of prairie communities, which contain many plant species listed by the Ohio Department of Natural Resources Natural Heritage Program as state endangered and threatened. The prairies at EOA are characterized by thin soils with dolomitic bedrock at or near the surface and an abundant variety of shade-intolerant native grasses and forbs. One hundred and twelve individual prairie openings were identified and mapped at EOA from three separate earlier surveys (Kapuska & Annala, unpublished data; Rankin, unpublished data; Minney, unpublished data).

Open grassland communities at EOA have been classified under a variety of names including central limestone glade (Faber-Langendoen 2001), cedar glades (Annala & Kapustka 1983), dolomite prairies, and alkaline barrens. These prairies are most likely a patchy part of a larger savanna-like ecosystem or "limestone barren" as described by Faber-Langendoen (2001). Because the prairie openings have been the showcase of the preserve and have been better described regionally than the larger barren system (Baskin & Baskin 2000), this study was limited to the simple goal of maintaining the open prairie component of these ecosystems. We will follow the classification developed regionally by Baskin and Baskin (2000) and refer to these areas as xeric limestone prairies or simply prairies or prairie openings.

Methods and Results

Because we are presenting an approach to prioritizing restoration actions that may not be familiar to restoration ecologists, we will describe step-by-step our decision analysis techniques and results. The reader is referred to Clemen (1996) for more details. A diverse group of individuals involved in management and decision-making for the limestone prairies were consulted during all aspects of the study, and their input was critical to our work.

Step 1. Modeling the Decision Situation

The first step in the decision analysis was to ask decision-makers how they determine which prairie to manage through expert meetings. We then developed with expert input a "fundamental objectives hierarchy," which is a graphical representation of the decision situation across all decision-makers involved (Fig. 1). Clemen (1996:532) explains that "fundamental objectives are the essential reasons that matter in any given decision context. Fundamental objectives are organized into a hierarchy in which the lower levels of the hierarchy explain what is meant by the higher (more general) levels."

In the fundamental objectives hierarchy, fundamental objectives are diagrammed as rectangles. The highest goal in this case study was to choose the prairie with the highest priority for management, and accordingly, this goal was the highest level on our fundamental objectives hierarchy. The next lower level in the hierarchy described how the prairie with the highest priority was defined, that is, decision-makers wanted to manage the prairie with the greatest need for management and with the highest quality. The quality of the prairie was defined by a number of factors at the next level of the hierarchy—connectivity to next closest prairie, abiotic variables, and species richness.

Step 2. Identifying and Measuring Attributes

Once we developed the fundamental hierarchy, we identified ways to measure each objective through consultation with the experts. In decision analysis, measures for each objective are known as "attributes" and are diagrammed as ovals in Figure 1. Although it is important to note that other attributes could have been used to measure each of the objectives, we chose this suite of attributes based on expert interview as well as data availability. We utilized rapid assessment field techniques to gather the attribute data in order to create a repeatable and rapid methodology for assessing each prairie. The data collection was conducted over 12 days in August 2001 with two to three staff per day.

The primary threat to prairies at EOA is the encroachment of woody species created by a lack of recent disturbance; therefore, the need for management at a given prairie opening was defined as the percentage of woody cover in the prairie opening. The need for management was measured using visual estimates of the percent woody cover on 50-m^2, fixed-radius plots. The number of plots sampled at each prairie opening was based on the size of the prairie opening; we added plots until at least 2% of the area of each prairie opening was sampled. The measurements of prairie area were made in Arc View 3.2 using 1-m resolution digital orthophotos (ESRI 1996). Plot locations within each prairie opening were determined by first locating the prairie opening's approximate center. Additional plots were located at a random distance and direction from the center plot. Plots were established no closer than 8 m from the prairie edge to sample the most open area of each prairie. Percent woody cover was estimated for both coniferous and deciduous cover in two size classes, less than 10-cm diameter at breast height (dbh) and greater than 10-cm dbh. The values from each of these four cover types were summed to arrive at a final percent woody cover value for each prairie opening.

The abiotic site attributes that were measured were aspect, slope, and geology. Aspect and slope are important in controlling ecosystem composition through irradiation levels, moisture levels, erosional regimes, and disturbance regimes (Perry 1994; Hix & Pearcy 1997; Iverson et al. 1997). These prairies are generally found on southern and

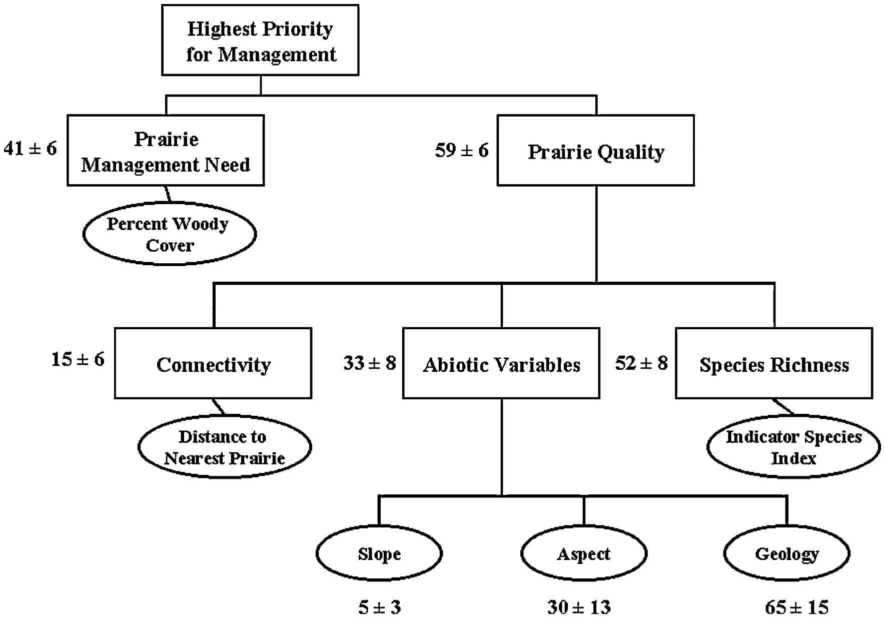

Figure 1. Fundamental objectives hierarchy, a graphical representation of how experts make restoration management decisions. Rectangles represent fundamental objectives. Ovals represent attributes or measures under each objective. Bold numbers to the left of each objective or attribute is the mean weight ± SE for all seven experts.

western exposures (Heikens & Robertson 1995; Faber-Langendoen 2001) and rarely on northern exposures (Braun 1928). In fact, Boettcher and Kalisz (1991) found that, over long time periods, sites with steep slope (>15%) and southerly exposures have had a greater amount of grasses and therefore persisted as prairie openings for longer time periods. Slope measurements were made using a clinometer at each woody cover sample plot and were then averaged for each prairie. Aspect measurements were taken from the center plot only. Geology is an important determinant of plant community distribution (Perry 1994). Limestone prairies are best developed on dolomite but can be found on other substrates. The geology attribute for each prairie was determined in Arc View using a bedrock geology data layer (Strittholt 1994; Strittholt & Boerner 1995).

Connectivity describes a prairie's landscape context (i.e., location in relation to other prairies) and was measured by distance to nearest prairie. Forested borders separated prairie openings from each other. Connectivity is an important factor in gene flow of both plants and animals between prairies; even small barriers between prairies can inhibit pollinator dispersal (Jackson 2003). Connectivity is also an indication of the feasibility of connecting each group of prairies into a larger ecosystem and of managing prairies as groups in management units. The connectivity attribute was defined as the distance from the center of a prairie opening to the center of the nearest neighboring prairie opening, using the "Nearest Features with Bearings" extension in Arc View (Jenness 2001).

Plant species richness is the number of different species found in a prairie opening and gives an indication of the current ecological condition of the prairie. The plant species richness attribute was measured in each prairie opening by determining the presence of 25 native indicator plant species, that is, the "indicator species index" (Table 1). Staff experts (D. Minney & R. Gardner 2001, The Nature Conservancy, Dublin, OH, personal communication) selected a list of indicator species based on three criteria: (1) the species represented a range of conservatism (see Swink and Wilhelm 1994, for definition of conservatism) from common to rare; (2) the species were easily identified during the time of year of the survey; and (3) the species were characteristic or "indicators" of the xeric limestone prairies. The number of indicator species present was based on a timed "walk-through" survey of the entire prairie opening, with 5 minutes being allocated toward the indicator species sampling for each percent woody cover plot in a prairie. Originally, experts indicated that the number of rare species was important in making management decisions. However, the census of rare species for each prairie would have required a large amount of time and expertise. We did have available information on rare species for a subset of previously surveyed prairies. To validate the indicator species index as a good surrogate for number of rare species, we performed a simple linear regression between number of rare species and the indicator species index (Minitab 1994). We found that the number of rare species was indeed significantly positively related to the indicator species index ($r^2 = 0.475$, $p < 0.001$; Fig. 2).

Table 1. Plant species used to measure plant species richness attribute or indicator species index.

Scientific Name	*Common Name*
Agave virginica L.	False aloe
Allium cernuum Roth	Nodding wild onion
Andropogon gerardii Vitman	Big bluestem
Aristida purpurescens Poiret	Arrowfeather
Asclepias verticillata L.	Whorled milkweed
Asclepias viridiflora Raf.	Green milkweed
Bouteloua curtipendula (Michx.) Torr.	Side oats grama
Dodecatheon meadia L.	Shooting star
Echinacea purpurea (L.) Moench.	Purple coneflower
Galactia volubilis (L.) Britton	Milk pea
Helianthus occidentalis Riddell	Western sunflower
Kuhnia eupatoroides L.	False boneset
Liatris aspera Michx. or *Liatris scariosa* (L.) Willd.	Lacerate or Northern blazing star
Liatris cylindracea Michx. or *Liatris squarrosa* (L.) Michx.	Few-headed or Plains blazing star
Linum sulcatum Riddell	Grooved yellow flax
Lobelia spicata Lam.	Spiked lobelia
Physostegia virginiana (L.) Benth.	Obedience
Ratibida pinnata (Vent.) Barnhart	Gray-headed coneflower
Ruellia humilus Nutt.	Hairy wild petunia
Schizachyrium scoparium (Michx.) Nash	Little bluestem
Silphium terebinthinaceum Jacq.	Prairie dock
Solidago rigida L.	Stiff goldenrod
Sorghastrum nutans (L.) Nash	Indian grass
Thalictrum revolutum DC.	Waxy meadow rue
Zizia aptera (A. Gray) Fern.	Heart-leaved golden alexander

Nomenclature follows Gleason and Cronquist (1991). Each pair of *Liatris* species was difficult to tell apart, and species were therefore paired together in the indicator species index.

A summary of the ecological attribute data for the prairie openings is presented in Table 2. Percent woody cover ranged from 150 to 4% (Figs. 3 & 4). Most of the prairies (64%) were found on south-, southwest-, or west-facing slopes. Of the remaining prairies, 16 were found on southeast slopes, 13 on northwest slopes, 7 on east slopes, 3 on north slopes, and 2 on northeast slopes. Sixty-nine percent of the prairies lie entirely on Cedarville Dolomite and an additional 21% on a mixture of Cedarville Dolomite and Estill Shale. Ten prairies were found entirely on Estill Shale, and one prairie was found on Ohio Shale.

Step 3. Modeling Expert Preferences

We assessed expert preferences during individual interviews conducted with seven employees involved in decision-making and preserve management at EOA, hereafter

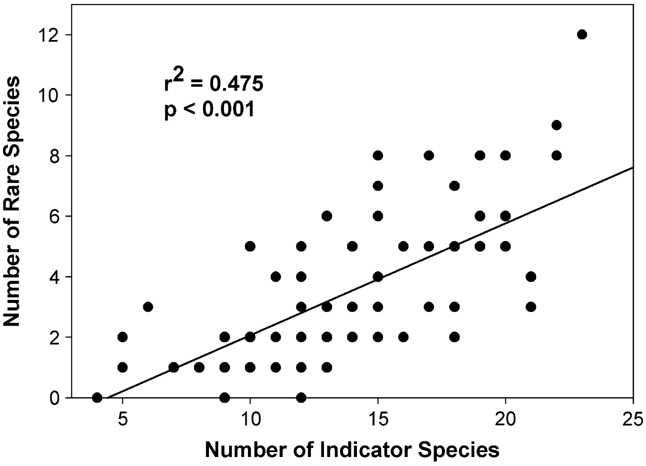

Figure 2. Relationship between indicator species index and number of rare species for 83 xeric limestone prairies.

referred to as experts. We interviewed experts separately because we expected consensus in one group interview to be difficult to obtain. Four of these experts were "on-the-ground" experts, with varying degrees of responsibility and with extensive experiential knowledge of the site. The three remaining experts were supervisory-level employees with advanced degrees in ecology, yet had little on-the-ground knowledge of the site. For the remainder of this paper, we will refer to these two groups of experts as technical experts and manager experts, respectively. We assessed utility functions and attribute weights (to be defined below) during expert interviews using Logical Decisions software (Logical Decisions 2001).

Modeling Expert Preferences: Assessing Utility Functions. First, we assessed utility functions for each of the attributes. The utility function is the mathematical representation of desirability of each expert for different values of each measured attribute. The utility functions for slope, geology, distance to nearest prairie, plant species richness, and percent woody cover attributes were assessed by expert interview using the certainty equivalent method (Clemen 1996). The process began by identifying the best and worst potential values for a given attribute. The best value was then assigned a utility of 1 and the worst a utility of 0. The mid–preference level was next determined by posing a series of "reference gambles" to the expert. In a reference gamble, the expert was presented with a decision. On the one hand, they could choose to take a gamble where they have a 50% probability of managing a prairie with either the worst or the best value for a given attribute. On the other hand, they could choose to manage the "sure thing"—a prairie with a known intermediate value of that attribute. To model the expert's preferences, the attribute value of the sure thing was adjusted over a series of reference gambles until the expert was indifferent between the gamble and the sure thing. The value of the sure thing at this point is called the indifference value, and this indifference value was then used to determine the mid–preference level by Logical Decisions (Logical Decisions 2001). The utility function was fit through the three points—0, 1, and the mid–preference level (Fig. 5). The utility value, ranging from 0 to 1, of all the collected ecological data can then be determined by its position on the curve. The utility for prairie aspect was measured by directly asking each expert to place a value from 0 to 1 on each of the eight cardinal directions based on their preference.

Table 2. Mean, standard error (SE), minimum, and maximum for each ecological measurement on 112 prairies.

Measurement	*$\overline{X}$(SE)*	*Minimum*	*Maximum*
Prairie opening size (acres)	0.86 (0.09)	0.05	4.45
Percent woody cover	42.5 (2.8)	4	150
Slope	10.7 (0.87)	0	39
Distance to nearest prairie (km)	0.20 (0.03)	0.04	1.35
Indicator species index	13.1 (0.46)	3	23

Utility functions for most of the attributes were fairly similar among experts. Connectivity or distance to nearest prairie was the utility function with the greatest difference among experts (Fig. 5). Four of the experts had utility functions similar to the mean of all experts, with a near-linear decrease in preference as distance increased. Experts 2–4 had preference functions for connectivity different from the mean of all experts. Expert 2 preferred highly all prairies with a nearest prairie less than ≈1 km. Expert 4 preferred highly only those prairies with a nearest prairie less than ≈.20 km. Expert 3 (not shown) had preferences similar to expert 4.

Modeling Expert Preferences: Assessing Weights. We next determined how important each of the components of the objectives hierarchy was to each expert by assessing weights through expert interview. Relative weights of goals and attributes were calculated through the use of trade-off analysis (Logical Decisions 2001). In this method, the decision-maker considered pairs of hypothetical prairies that differ in value on exactly two of the attributes. For example, prairie A had the highest value for diversity but the lowest value for species richness, and prairie B had the reverse. If the expert preferred the two hypothetical prairies equally, then the two attributes were assigned equal weights. If the expert preferred one of the hypothetical prairies to the other, then the low value of the least preferred prairie was improved until the expert preferred both prairies equally. Weights were then calculated by the software program (Logical Decisions 2001) based on the degree to which each value had to be changed. Weights for all components of the objectives hierarchy were derived through a series of these pair-wise comparisons. Possible interactions between attributes were assessed using the

Figure 3. Photograph of prairie with 130% woody cover. Photo by A. Maruyama.

"Additional Tradeoff" method (Logical Decisions 2001) for two experts only.

Weights for the mean of all experts for each component of the objectives hierarchy are found in Figure 1. Species richness was the greatest contributor to prairie quality, followed by geology, connectivity, aspect, and slope. We found no interaction between attributes for the two experts assessed.

Step 4. Determining Priority Scores

Last, we determined priority or "final utility" scores for all prairies. Because we expected differences between individuals, we determined priority scores for each of the seven experts, as well as the mean of all the seven experts. In addition, because there was a perception that the types of experts would differ, we determined priority scores for the mean of the four technical experts and of the three manager experts. The mean utility function mid–preference level and mean weights were used for means of more than one expert. Because there were no significant interactions in expert preference between attributes, we used an additive multiattribute utility function to determine priority scores (Clemen 1996:536). In accordance with this additive function, final utility scores for individual prairies were calculated by the following process: (1) the collected ecological data were converted into utility units using the utility function for each attribute; (2) the utility value for each attribute in a given prairie was multiplied by the weight for that attribute to attain a weighted score; and (3) the weighted scores for each attribute at a given prairie were added.

Figure 4. Photograph of prairie with 4% woody cover. Photo by A. Maruyama.

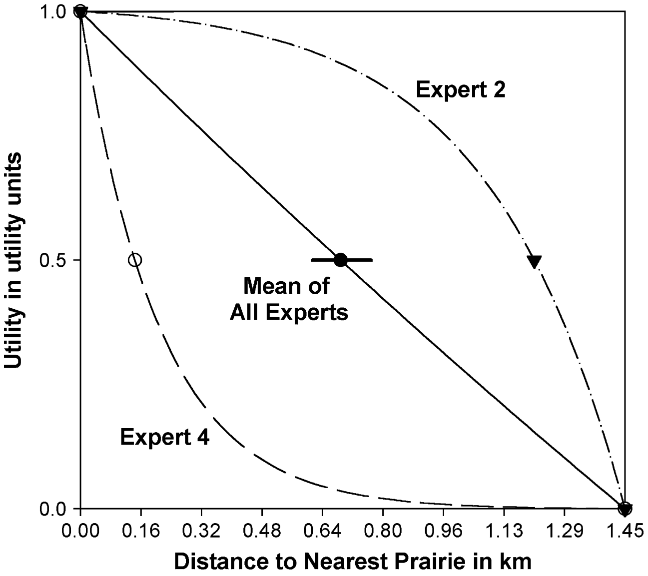

Figure 5. Utility functions for distance to nearest prairie for expert 2, expert 4, and mean of all seven experts. Horizontal line around mean of all experts represents the standard error of this mean.

Thirty-two of the prairies are managed singly in management units. The remaining majority of the prairies are managed as groups in management units for logistical reasons. The number of prairies in each of the 54 total management units ranges from one to seven. We determined a priority score for each management unit by finding the highest individual prairie priority score for each management unit. We then ranked management units by this score. To limit the presentation of results for this article, we determined the mean rank of each management unit across all the seven experts and selected the top 10 of these units (Table 3). For all figures in this article, we are presenting the data from the highest scoring individual prairie in these top 10 management units.

Table 3. Management unit ranks of 10 management units for the mean of all experts (All), mean of all technical experts (Techs), and mean of all manager experts (Mgrs).

ID No.	*No. of Prairies*	*All*	*Techs*	*Mgrs*	$\overline{X}$ *Rank*
19	1	1	1	1	1
83	4	2	2	3	2.3
97	1	3	7	2	4
112	7	4	5	5	4.7
81	1	5	6	6	5.7
7	1	7	10	9	8.7
44	5	6	18	4	9.3
93	6	8	3	17	9.3
54	2	9	8	12	9.7
78	2	10	4	20	11.3

ID No. is the prairie identification number of the top scoring prairie in each management unit. Mean rank is mean rank across all individual experts. Units are ordered in increasing mean rank number. No. of Prairies is number of prairies in the management unit.

The final utility scores for the mean of all experts, the mean of the technical experts, and the mean of the manager experts are presented in Figure 6. In this figure, each final utility score is graphically broken down into the contribution from each separate attribute utility, which is a combination of the utility function and weight for each attribute. Significant differences between experts and between the three expert groups (manager experts, technical experts, and all experts) were determined by performing a series of one-way analysis of variances (ANOVAs) on proportional contribution of each attribute toward the final utility score for all prairies. ANOVAs were followed by Tukey's test to determine significance between treatment means. Data were arcsine square root transformed in order to meet model assumptions of normality and homoscedasticity. To compensate for the multiple use of the same data, the significance level was adjusted to 0.01 for the Tukey's test. The results of the statistical analyses are presented in Table 4. There were significant differences between experts, with no discernable pattern. For the combined data, percent woody cover, geology, aspect, and slope were more important to manager experts, whereas indicator species index and distance to nearest prairie were more important to technical experts. The average of all experts fell in the middle as predicted for most attributes, yet was not significantly different from that of the technical experts for percent woody cover and indicator species index.

Despite these differences among experts, there is a good consensus on priority of the top quarter of management units. In fact, for the 18 units ranked in the top third of all management units, 7 are in the top third for all seven experts, 4 are in the top third for six experts, 3 are in the top third for five experts, and two are in the top third for four experts. For the combined group data, 13 of the 18 prairies are in the top third for both technical experts and manager experts. There are similar trends in agreement for middle and bottom third of the management unit rankings. Fifteen of the top 18 prairies were in common between the all-expert grouping and the technical experts and between the all-expert grouping and manager experts. Therefore, using the mean of all experts provides agreement for both groups of experts.

Step 5. Performing Sensitivity Analysis

We performed a sensitivity analysis for the results from the mean of all experts to determine how the rank of the highest individual prairie in the top 10 ranked management units may be sensitive to changes in weights. We used sensitivity diagrams to display how rankings would change as weights for each of the attributes change from 0 to 100 (Logical Decisions 2001). Figure 7 displays the sensitivity diagrams for each of the attributes. If lines are parallel, then rankings are not sensitive to changes in

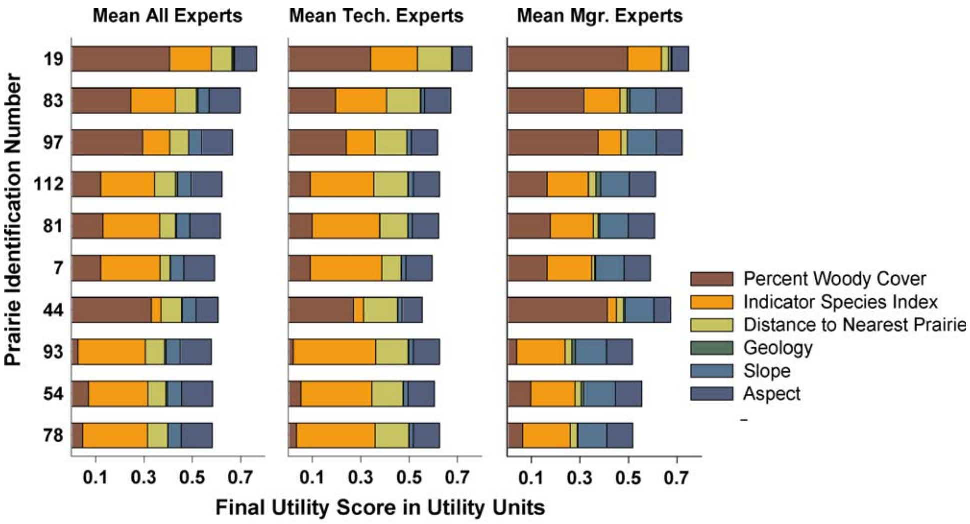

Figure 6. Highest scoring individual prairies of top 10 management units for mean of all experts, mean of technical experts (tech. experts), and mean of manager experts (mgr. experts). Total scores are broken into utility scores for each attribute to illustrate how much each ecological measure contributes to the final utility score.

weights. The greater the amount of line crossing, the more the rankings change with changing weights. The bold vertical line indicates the weight for the mean of all experts for that attribute. The diagrams for percent woody cover and indicator species index show the greatest amount of sensitivity to changes in weights because rankings will significantly change if weights change more than about 10 units. In contrast, change in weighting of measures such as geology, slope, aspect, and distance to nearest prairie would change our rankings of prairies very little, unless changes in weights were in the range of 15–40 units. This sensitivity analysis gives us confidence that our rankings are rather robust because standard error for our weights across all individual experts was in the range of only 6–8 units (Fig. 1).

Discussion

Decision analysis allowed the integration of ecological theory, objective ecological data, and subjective expert opinion to make restoration decisions. The end result of this study was a ranked list of management units according to the decision model and field data collected. All prairies included in this study were considered important by experts, and the ranked list does not imply that one management unit or prairie is "better" than another. The ranked list simply gives an idea of what prairies should be managed immediately or perhaps more intensely according to expert preferences. Managers at EOA make decisions on which prairies to focus restoration based on the balance between quality of prairie, an integrative measure of species richness, geology, aspect, slope, and connectivity, and the need for

Table 4. ANOVA results for the proportional contribution of each attribute toward the final utility score for all prairies.

	df	*F*	*Comparisons*
Differences among experts			
Percent woody cover	6, 777	71.71	7 > 1, 6 > 3, 4, 5 > 2
Indicator species index	6, 777	213.86	2 > 1, 6 > 4, 5 > 3, 7
Geology	6, 777	1344.94	5 > 4 > 3 > 1, 7 > 2, 6
Distance to nearest prairie	6, 777	630.48	3 > 2 > 1, 7 > 4 > 5, 6
Aspect	3, 444	305.35	7 > 6 > 1, 2*
Slope	3, 444	188.79	7 > 1, 6 > 2*
Differences among combined expert groups			
Percent woody cover	2, 333	16.34	Mgrs > All, Techs
Indicator species index	2, 333	14.02	Techs, All > Mgrs
Geology	2, 333	12.88	Mgrs > All > Techs
Distance to nearest prairie	2, 333	450.16	Techs > All > Mgrs
Aspect	2, 333	356.81	Mgrs > All > Techs
Slope	2, 333	63.58	Mgrs > All > Techs

df = degrees of freedom. "Comparisons" summarizes results of Tukey's tests for each expert, designated by number for differences among experts and designated by group (*Mgrs* = manager experts, *Techs* = technical experts, and *All* = all experts). All ANOVAs were significant and had a *p* value of less than 0.001.
*Experts 3–5 gave a weighting of zero to slope and aspect, so these experts were not included in relevant ANOVAs.

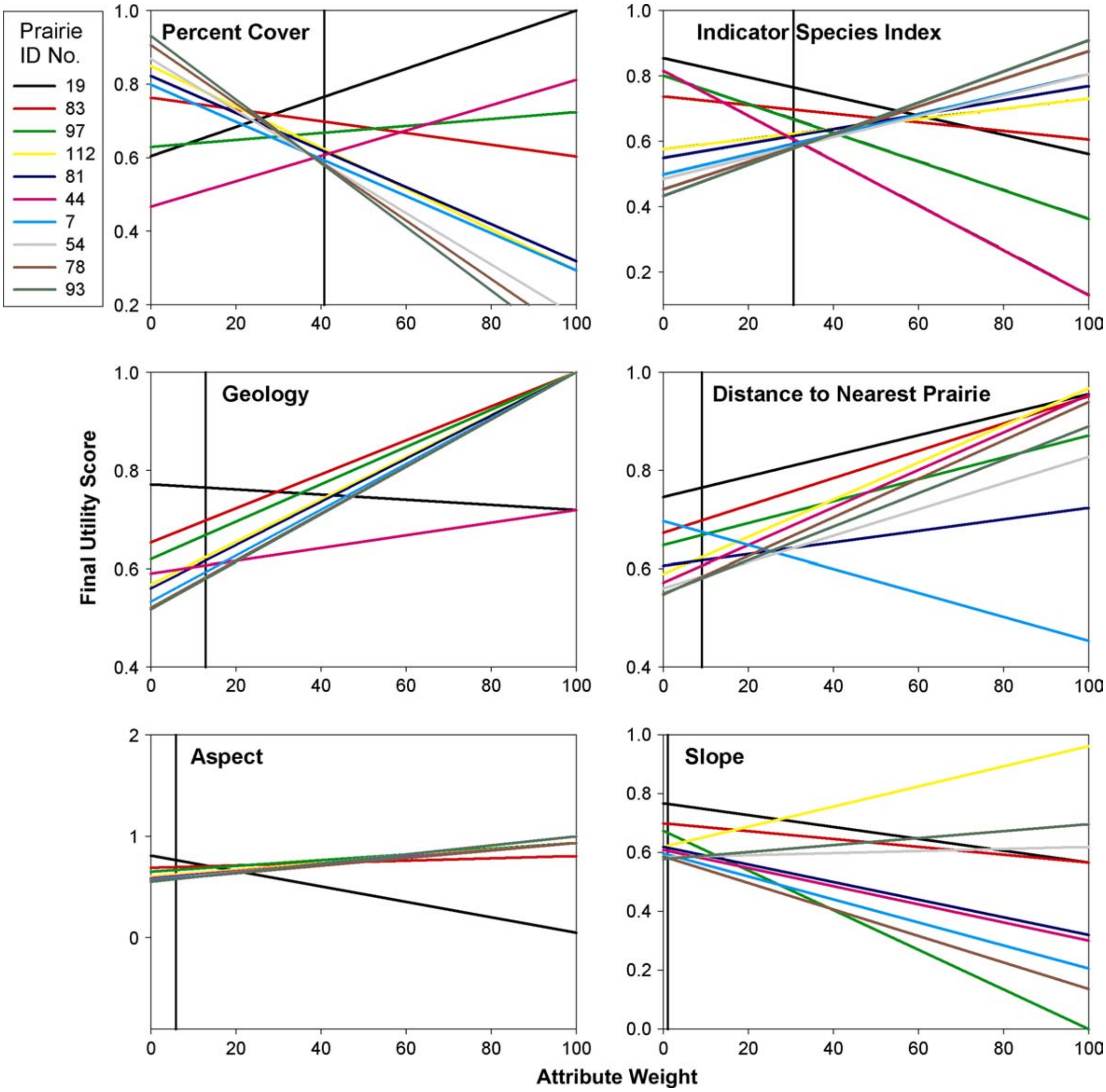

Figure 7. Sensitivity analyses for six attributes of highest scoring individual prairies of top 10 management units for mean of all experts. Lines indicate how the value and relative rankings of prairies change as weights vary from 0 to 100 for a given attribute. If lines are parallel, then rankings are not sensitive to changes in weights. The greater the amount of line crossing, the more the rankings change with changing weights. The bold vertical line indicates the current weighting for that attribute. Numbers within each graph label lines with the prairie identification number of the highest scoring individual prairies of each management unit. Only lines that change rankings over varying ranges of weighting during the sensitivity analysis are labeled for figure clarity.

management. We found that species richness is an important factor in the decision-making process, a reflection of the mission of biodiversity protection of The Nature Conservancy (TNC 2001). Protecting species-rich areas can be an efficient way of achieving biodiversity conservation (Myers et al. 2000), although this technique does not conserve the full range of biodiversity (Kareiva & Marvier 2003).

Decision analysis is useful as a consensus-building tool (Maguire & Boiney 1994). Those responsible for making management decisions at the EOA come from a variety of backgrounds and training and have varied experience and priorities that have led to differences in opinion on how prairie restoration should be carried out. Bringing the group together for planning meetings, gathering the opinions and preferences of all experts through individual interviews, and then combining results allowed for the inclusion of all available expertise. Decision analysis clearly shows the differences in how individuals make decisions. In this way, the major differences in decision-making between individuals can be addressed and consensus reached. Despite the differences in opinion and apparent lack of consensus between experts, experts and expert groups ranked management units very similarly. In fact, experts, both as individuals and in groups, had strong agreement on management units found in the top, middle, and bottom third of the ranked units.

This survey of the prairies at EOA represents the first systematic and quantitative survey of all the currently owned prairie openings at EOA within a single season. As such it is extremely useful because it provides a source of easily comparable information on each of the prairie openings as well as a baseline of information by which future studies can be evaluated. In addition, this data collection can be reproduced in the future to quickly determine the efficacy of current management techniques. Prairies were found on south- and west-facing slopes, primarily on dolomite, as predicted. Because the indicator species index is correlated with the rare species, we have confidence that the created indicator species index was indeed a good measure for capturing the number of rare species, a particular concern of experts.

It is important to note that this prioritization scheme is still based largely on expert opinion. We simply created a model to describe the way that experts have made these restoration decisions, which served to make these decisions more transparent and quantitative. Although decision analysis provides structure and guidance for systematic thinking in difficult situations, it should be used with a certain degree of caution. Decision analysis is a simplification of complex systems and thought processes and thus may not fully capture the intricacies in making decisions. However, it would require rather large changes in the preferences of the experts in relation to percent cover and species richness to result in a significant change in the final rankings of the prairies, as illustrated in our sensitivity analysis.

Additionally, decision analysis is only as accurate as the input data. The data used in the analysis were by necessity rapidly assessed, which incorporates a certain amount of error that must be considered. We found that future field validation of the geology layers is necessary because the prairie on Ohio Shale was misclassified. This is due to the large mapping scale (30 × 30–m grids) and subsequent inability to map geologic inclusions, as well as due to inaccuracies in mapping. In order to test the effect of this misclassification, we changed the geology value for this prairie. We found that it was still ranked solidly in the bottom quarter of all prairies partly because geology has a low weight, partly because geology did not vary much between prairies, and partly because this prairie had low values for the percent woody cover attribute. Further, because this prairie was ranked very low compared to others in the same management unit, the misclassification had no effect on the management unit ranking. In addition, we measured aspect at only the center plot. Some of these prairies wrapped around a hill and therefore a single aspect may not be adequate. Future studies could use geographic information systems (GIS) to get a mean aspect for the entire prairie opening.

Decision analysis is an iterative process. Fortunately, the software is user-friendly and easily updated for future improvements. There are improvements we would make in future iterations. First, we would use the existing results to show experts how close their agreement really was and the major areas where there was disagreement. We would then use a group interview to get experts to combine all their expertise into one agreed-upon analysis to achieve greater consensus. In the meantime, the mean expert data do provide very good agreement between experts and can be used with confidence to prioritize current restoration activities. The utility function for aspect was directly assessed by experts; in future iterations, we would use the gamble approach of the probability equivalent method (Yates 1990), which is similar to the certainty equivalent approach. This deficiency in our study had little effect because experts weighted slope very little. We used an additive model for our multiadditive utility function, which assumes that interactions are negligible, to ease the combination of expert data. We tested for interactions after the study was complete with only two experts. We would test for interactions more fully with the entire group. In addition, we discovered that our fundamental objectives hierarchy may not have been complete. In the future, we would also include size of prairie in our model, as we discovered at the conclusion of our study that size appeared to be important to experts. Some prairies cost more than others to restore, in part due to constraints on whether a prairie can be burned or cut, as well as if prairies are managed singly or in groups. Cost of restoration can be included in future iterations to consider this factor.

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LITERATURE CITED

Anderson, R. C., J. S. Fralish, and J. M. Baskin, editors. 1999. Savanna, barrens and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, United Kingdom.

Annala, A. E., J. D. Dubois, and L. A. Kapustka. 1983. Prairies lost to forests: a 33-year history of two sites in Adams County, Ohio. Ohio Journal of Science **83:**22–27.

Annala, A. E., and L. A. Kapustka. 1983. Photographic history of forest encroachment in several relict prairies of the Edge of Appalachia Preserve System, Adams County, Ohio. Ohio Journal of Science **83:**109–114.

Bailey, R. G. 1994. Ecoregions of the United States. USDA Forest Service, Washington, D.C.

Baskin, J. M., and C. C. Baskin. 2000. Vegetation of limestone and dolomite glades in the Ozarks and Midwest Regions of the United States. Annals of the Missouri Botanical Gardens **87:** 286–294.

Baskin, J. M., C. C. Baskin, and E. W. Chester. 1994. The big barrens region of Kentucky and Tennessee: further observations and considerations. Castanea **59:**226–254.

Boettcher, S. E., and P. J. Kalisz. 1991. The prairies of the E. Lucy Braun Preserve, Adams County, Ohio: a soil study. Ohio Journal of Science **91:**122–128.

Braun, E. L. 1928. Vegetation of the mineral springs region of Adams County, Ohio. Ohio Biological Survey Bulletin **15:**383–517.

Clemen, R. T. 1996. Making hard decisions. Duxbury Press, Belmont, California.

Cohan, D., S. M. Haas, D. L. Radloff, and R. F. Yancik. 1984. Using fire in forest management: decision making under uncertainty. Interfaces **14:**9–16.

ESRI (Environmental Systems Research Institute). 1996. Using Arc View GIS. Environmental Systems Research Institute, Redlands, California.

Faber-Langendoen, D., editor. 2001. Plant communities of the Midwest: classification in an ecological context. Nature Serve, Arlington, Virginia.

Gleason, H. A., and A. Cronquist. 1991. Manual of vascular plants of northeastern United States and adjacent Canada. The New York Botanical Garden, Bronx.

Haney, A., and R. L. Power. 1996. Adaptive management for sound ecosystem management. Environmental Management **20:**879–886.

Heikens, A. L., and P. A. Robertson. 1995. Classification of barrens and other xeric openings in Southern Illinois. Bulletin of the Torrey Botanical Club **122:**203–214.

Hix, D. M., and J. N. Pearcy. 1997. Forest ecosystems of the Marietta Unit, Wayne National Forest, southeastern Ohio: multifactor classification and analysis. Canadian Journal of Forestry **27:**1117–1131.

Iverson, L. R., M. E. Dale, C. T. Scott, and A. Prasad. 1997. A GIS-derived integrated moisture index to predict forest composition and productivity of Ohio forest (USA). Landscape Ecology **12:**331–348.

Jackson, T. 2003. Pollen-mediated gene flow and genetic variation within *Manfreda virginica* populations occurring in Adams County, Ohio. M.S. thesis. Ohio University, Athens.

Jenness, J. 2001. Nearest features with bearings ArcView software extension. Jenness Enterprises, Flagstaff, Arizona.

Kareiva, P. M., and M. Marvier. 2003. Conserving biodiversity coldspots. American Scientist **91:**344–352.

Logical Decisions. 2001. Logical Decisions© for Windows™ manual. Logical Decisions, Golden, Colorado.

Maguire, L. A. 1986. Using decision analysis to manage endangered species populations. Journal of Environmental Management **22:** 345–360.

Maguire, L. A., and L. G. Boiney. 1994. Resolving environmental disputes: a framework incorporating decision analysis and dispute resolution techniques. Journal of Environmental Management **42:**31–48.

Minitab. 1994. Minitab reference manual: Release 10. Mintab, Inc., State College, Pennsylvania.

Myers, N. R., A. Mittermeier, C. G. Mittermeier, G. A. B. de Fonesca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403:**853–858.

Norton, G. A., and B. H. Walker. 1985. A decision analysis approach to savanna management. Journal of Environmental Management **21:**15–31.

NRC (Natural Research Council). 1992. Restoration of aquatic ecosystems: science, technology and public policy. National Academy Press, Washington, D.C.

Parrish, J. D., D. P. Braun, and R. S. Unnasch. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. Bioscience **53:**851–860.

Perry, D. A. 1994. Forest ecosystems. The Johns Hopkins University Press, Baltimore, Maryland.

Pieterse, N. M., A. W. M. Verkroost, M. Wassen, H. Olde Venterink, and C. Kwakernaak. 2002. A decision support system for restoration planning of stream valley ecosystems. Landscape Ecology **17:**69–81.

Strittholt, J. R. 1994. A regional nature reserve design using geographic information systems for the Edge of Appalachia, Adams County, Ohio. Ph.D. dissertation. Ohio State University, Columbus.

Strittholt, J. R., and R. E. J. Boerner. 1995. Applying biodiversity gap analysis in a regional nature reserve design for the Edge of Appalachia, Ohio (USA). Conservation Biology **9:**1492–1505.

Swink, F. A., and G. S. Wilhelm. 1994. Plants of the Chicago region. Indiana Academy of Science, Indianapolis.

TNC (The Nature Conservancy). 2001. Conservation by design: a framework for mission success. The Nature Conservancy, Arlington, Virginia.

Walters, C. J, and C. S. Holling. 1990. Large-scale managements and learning by doing. Ecology **71:**2060–2068.

Wyant, J. G., R. A. Meganck, and S. H. Ham. 1995. A planning and decision making framework for ecological restoration. Environmental Management **19:**789–796.

Yates, J. F. 1990. Judgement and decision making. Prentice Hall, Englewood Cliffs, New Jersey.