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Research paper

Choosing between alternative placement strategies for conservation buffers using Borda count

Zeyuan Qiu[a,*], Michael G. Dosskey[b], Yang Kang[c]

[a] Department of Chemistry and Environmental Science, New Jersey Institute of Technology, Newark, NJ 07102, United States
[b] USDA Forest Service, National Agroforestry Center, Lincoln, NE, United States
[c] Department of Statistics, Columbia University, New York, NY, United States

HIGHLIGHTS

- The criteria weights are similar whether confidence in ranking is considered or not.
- The weight for controlling soil erosion is 0.31, the highest among four criteria.
- The weight for enhancing wildlife habitat is 0.16, the lowest among four criteria.
- The Kappa values comparing Two MCDM methods are between 0.614 to 0.655.
- Both MCDM methods are valid tools in prioritizing buffer placement.

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ABSTRACT

There is inherent ambiguity when comparing decision criteria in multi-criteria decision-making (MCDM). A fuzzy Borda count was developed to take into account some of the ambiguity and derive criteria weights by linguistically comparing decision criteria. This study extends the fuzzy Borda count to take into account agents' confidence in their preferences for criteria weights. The procedure is applied to prioritize agricultural lands for conservation buffer placement using multiple criteria in the Raritan River Basin in New Jersey. These criteria, which include soil erodibility, hydrological sensitivity, wildlife habitat, and impervious surface, capture the conservation buffers' ecosystem services in terms of reducing soil erosion, controlling runoff generation, enhancing wildlife habitat, and mitigating stormwater impacts, respectively. A survey was conducted of conservation professionals including federal employees at NRCS, state and local agencies and nongovernmental environmental organizations to elicit agents' preferences for multiple benefits of conservation buffers using a fuzzy pairwise comparison method. The study compares the fuzzy MCDM procedure to a class-based MCDM procedure for prioritizing agricultural lands for conservation buffer placement. The comparative results show that both procedures have their advantages and disadvantages, but generate comparable prioritization results. Further research is needed to improve the proposed fuzzy MCDM procedure to handle missing values in eliciting agents' preferences for comparing multiple criteria.

1. Introduction

Deciding between alternative strategies for watershed restoration and conservation can be challenging when the alternatives are complex, characterized by diverse goals and multiple criteria, and there is uncertainty in the outcomes of each alternative. Goals typically include improving water quality and wildlife habitat, among other improvements, while limiting costs. Reaching a decision can become even more complicated when there are multiple decision makers, such as members of a council, committee, or other watershed planning body. Complex decision alternatives and multiple decision-makers, especially in contentious settings, can lead to decision paralysis. While each alternative strategy may be more or less optimum with regard to its goals, each decision-maker may have a preference for one particular goal or set of goals that differs greatly from the preferences of others. There are also varying degrees of confidence among decision makers in predicted outcomes of some alternatives. Widely divergent and conflicting

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* Corresponding author.
E-mail address: zeyuan.qiu@njit.edu (Z. Qiu).

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preferences among decision-makers can prevent the group from reaching consensus agreement on a single strategy (LaChapelle, McCool, & Patterson, 2003). In such situations, it becomes important to employ a structured process for decision-making that facilitates identification of a group-preferred alternative and a group decision (Zeleny, 1982).

Multiple Criteria Decision Making (MCDM) is a branch of modern decision science that encompasses techniques that can be employed in complex decision environments for identifying and selecting an optimum alternative (Gwo-Hshiung, 2011). Some of these techniques have been used in natural resources and ecosystem management to help decision-makers evaluate tradeoffs among several criteria (Geng & Wardlaw, 2013; Hermans, Erickson, Noordewier, Sheldon, & Kline, 2007; Nyeko, 2012; Prato, 1999; Qiu, 2005; Randhir, O'Connor, Penner, & Goodwin, 2001; Yilmaz & Harmancioglu, 2010). Of particular interest in watershed conservation planning are objective techniques for understanding the preferences of multiple decision-makers. In MCDM, decision makers' preferences for criteria are often expressed as criteria weights and the way in which those weights are determined can profoundly affect the alternative that is ultimately chosen.

Several methods have been developed for eliciting decision-makers' preferences for criteria and assigning criteria weights (McPhee & Yeh, 2004; Stroppiana, Boschetti, Brivio, Carrara, & Bordogna, 2009; Torra, 1997; Yager, 1995; Zarghami & Szidarovszky, 2009). For example, each decision-maker can directly express preference for a specific criterion using a crisp number such as 0.1, fuzzy number such as (0, 0.1, 0.2), or linguistic variables such as "very important" or he/she could order the criteria such as: $w_2 > w_1 > w_3$, where w_1, w_2 and w_3 are the weights for criteria 1, 2 and 3, respectively. The criteria weights for the group can then be determined through optimization techniques (Xu, 2005). Another popular method for determining criteria weights for a group is the Analytic Hierarchy Process (AHP; Saaty, 1977, 1980). In the AHP, each decision-maker is asked to make pairwise comparisons of the criteria, in crisp, fuzzy or linguistic form, which expresses the extent to which one criterion is more/less important than another criterion. Results of all pairwise comparisons are then used to determine the criteria weights.

We propose a simpler method for eliciting individual preferences, determining group criteria weights, and identifying a group-preferred alternative. The method is a refinement of the Borda count. This refinement develops criteria weights directly from judgment matrices generated from only one round of pairwise comparisons using linguistic variables. The Borda count was originally developed as a consensus-based, rather than a majoritarian, election method in which voters rank multiple candidates for public office in order of preference and winners are based on these results. More recently, this method has found use in group decision-making where the "winner" is the most preferred alternative. Every decision maker ranks each alternative relative to every other alternative rather than "voting" on only the most preferred alternative (Dummett, 1998). The Borda count method selects the alternative that stands the highest on average in the decision makers' preference orderings (Black, 1958, 1976; Mueller, 1979). In this way, the Borda count guides decision-makers to a broadly acceptable or consensual alternative rather than to one preferred by a majority.

There have been significant adaptations of the Borda count to make it more useful in specific contexts. For example, the Borda count was refined to handle situations when decision-makers (voters) are indifferent to some alternatives (candidates) (Black, 1958, 1976; Gärdenfors, 1973). The valued relations were introduced into the Borda count to aggregate fuzzy relations (Marchant, 1996, 1998, 2000). In addition, it was extended to analyze decision alternatives using linguistic or fuzzy numbers, rather than precise numbers, which capture the imprecise nature of human evaluations (García-Lapresta & Martínez-Panero, 2002; García-Lapresta, Martínez-Panero, & Meneses, 2009; Nurmi, 2001). In this study, the linguistic context developed by García-Lapresta et al. (2009) is extended further to take into consideration decision-makers' confidence in their linguistic comparisons of decision criteria. This approach can be treated as a special case of the majority rules based on difference in support as described by Llamazares et al. (2013). This approach can make the Borda count method more amendable to watershed planning and the selection of a broadly preferred conservation strategy. This study has two objectives: (1) to describe an adaptation of the Borda count method that simplifies the process of eliciting preferences and developing criteria weights; and (2) to demonstrate the method by using it to determine a broadly acceptable strategy for the placement of conservation buffers in the Raritan River Basin in New Jersey.

Table 1
Nine linguistic labels for comparing the pairs of decision alternatives and criteria.

Label	Level of Preference	TFN	V(t)
l_0	Absolutely less important	(0, 0, 0, 0)	0.0000
l_1	Much less important	(0, 0.02, 0.05, 0.11)	0.0417
l_2	Somewhat less important	(0.05, 0.11, 0.17, 0.25)	0.1433
l_3	Less important	(0.17, 0.25, 0.34, 0.44)	0.2983
l_4	Equally important	(0.34, 0.44, 0.56, 0.66)	0.5000
l_5	More important	(0.56, 0.66, 0.75, 0.83)	0.7017
l_6	Somewhat more important	(0.75, 0.83, 0.89, 0.95)	0.8567
l_7	Much more important	(0.89, 0.95, 0.98, 1)	0.9583
l_8	Absolutely more important	(1, 1, 1, 1)	1.0000

2. Borda count method for fuzzy multiple criteria decision making

Following García-Lapresta et al. (2009), let $X = \{x_1, x_2, \ldots, x_n\}$ be a set of decision alternatives for which m agents show their preferences over the pairs in X in a linguistic manner, where $m \geq 2$ and $n \geq 2$. Let $L = \left\{l_0, l_1, \ldots, l_s\right\}$ be a set of linguistic labels, where $s \geq 2$, ranked by an preference order: $l_0 < l_1 < \ldots < l_s$. There should be an intermediate label representing indifference between alternatives around which the rest of the labels are defined in a symmetric manner as in Table 1. Therefore, the number of labels, $s + 1$, will be odd and, consequently, $l_{s/2}$ is the central label. Suppose that each agent $k \in \left\{1, 2, \ldots, m\right\}$ compares all the pairs in X and declares levels of preference by means of a linguistic binary relation $R^k : X \times X \rightarrow L$. The ij^{th} element of R^k is $r_{ij}^k = R^k(x_i, x_j)$, which designates the degree of preference with which agent k prefers x_i over x_j, expressed using a linguistic label l_h, where $l_h \in L$. It is assumed that linguistic preference relations satisfy the following reciprocity condition: $r_{ij}^k = l_h \Leftrightarrow r_{ji}^k = l_{s-h}$

García-Lapresta et al. (2009) further suggest that the linguistic labels can be represented through trapezoidal fuzzy numbers (TFNs), which can capture the vagueness of such linguistic assessments (Delgado, Vila, & Voxman, 1998). Given any TFN, $t = (a, b, c, d)$, the value, $V(t)$, and ambiguity, $A(t)$, of that TFN are real numbers and can be calculated as follow:

$$V(t) = \frac{c+b}{2} + \frac{(d-c)-(b-a)}{6} \tag{1}$$

$$A(t) = \frac{c-b}{2} + \frac{(d-c)+(b-a)}{6} \tag{2}$$

The TFNs can be compared through their values by

$$t \succ t' \Leftrightarrow \begin{cases} V(t) > V(t')\, or \\ V(t) = V(t')\, and\, A(t) < A(t') \end{cases} \tag{3}$$