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A Multicriteria Decision Analysis For Identifying Priority Conservation Areas For Grassland Birds

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A Multicriteria Decision Analysis for Identifying Priority Conservation Areas for Grassland Birds

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Abstract - Biodiversity conservation frequently competes with the needs of society for agricultural production and development. However, properly designed and efficiently implemented conservation programs can be used to integrate wildlife and human needs. We tested the efficacy of multicriteria decision analysis as a tool to select priority areas for conservation in human-dominated landscapes using grassland birds in the northeastern US as a test case. We created detailed GIS layers including landscape- (forest, grassland, development, and roads within a 3000-m buffer around each grassland patch) and patch-level (size, management, and conservation status) criteria important in grassland bird habitat selection and conservation. We developed a set of 36 scenarios in which we varied the relative weights associated with different patch attributes. A sensitivity analysis showed that the habitat quality score for each patch was less sensitive to changes in weights at the landscape level, and more sensitive to changes at the patch level. Integrating the GIS dataset into a multicriteria decision analysis framework, we produced maps in which grassland patches were ranked based on habitat quality and used these maps to identify priority conservation areas. Grassland blocks of >100 ha were mainly concentrated in 2 regions and were identified as priority sites that had the highest quality values for grassland bird conservation. This approach resulted in maps that managers can use to focus conservation efforts. The integration of GIS with multicriteria decision analysis can serve as a model for researchers to help set priorities for land conservation for other species and in other regions.

Introduction

Conservation of biodiversity has been pursued traditionally by protecting tracts of land with high biodiversity (Margules and Pressey 2000). However, human domination of ecosystems is so pervasive that the conservation of biodiversity cannot be achieved by setting aside land only for this purpose: there is simply no more land to be protected that is not required for other functions (Kareiva et al. 2007). Many species in need of protection, such as charismatic megafauna and declining bird species, require large areas to maintain viable populations. Thus, the conservation of healthy, functioning ecosystems in which biodiversity is maintained in the presence of humans requires the integration of reserve design rules and ecosystem management approaches at the species, ecosystem, and landscape levels (Knight and Cowling 2007, Margules and Pressey 2000, Meffe et al. 2002).

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Agricultural landscapes are examples of this approach, as the loss of native prairie ecosystems has forced many species to use human-modified habitats across significant portions of their range. One vertebrate group, grassland birds, has shown consistent declines throughout North America (Cunningham and Johnson 2006, Herkert 1994, Perlut et al. 2008, Sauer et al. 2014, Walk and Warner 1999), with population declines >1.1% per year between 1966 and 2014 (Sauer et al. 2014). At that rate of decline, total population sizes would be reduced by 50% in less than 65 years. The decline of grassland birds is particularly significant in the eastern United States where ~70% of these species are declining (Sauer et al. 2014). Multiple causes have been proposed to explain the decline of grassland birds, but habitat loss and declining habitat quality are recognized as key elements (Bollinger et al. 1990, Cunningham 2005, Herkert 1994, Perlut et al. 2008, Vickery et al. 1994).

In the northeastern United States, grassland birds use agricultural fields and fallow grassland patches for breeding habitat. Nearly all of these patches are found on private land (Cuzio et al. 2013) and are managed in a variety of agricultural schemes that may be at odds with conservation of grassland bird populations (Troy et al. 2005). Thus, in this region, the conservation of grassland birds competes with societal needs of agricultural production. As such, the goal of maximizing biodiversity must be considered with the goal of minimizing costs to society to make grassland habitat protection logistically, politically, and economically feasible (Cameron et al. 2008). Several conservation programs offered through the Natural Resources Conservation Service (NRCS) provide financial incentives to landowners to improve habitat quality for grassland birds (NRCS 2008). However, the programs are voluntary, and coordination and implementation have not been applied in a spatially targeted manner that focuses on regions with high grassland bird density. A systematic and repeatable method to delineate priority conservation areas could maximize the conservation benefits of these programs.

We identified high impact areas for conservation of grassland birds by using multicriteria decision analysis (MCDA), a framework that integrates manager objectives with more-theoretical reserve design techniques (Belton and Stewart 2002). MCDA is a procedure that uses objective criteria to evaluate a set of alternatives to reach a meaningful and transparent solution. The core component of MCDA involves deconstructing the problem into manageable components that are analyzed separately and then integrated to obtain a solution (Malczewsky 1999). MCDA can combine socioeconomic, ecological, and governance criteria and can involve collaborative decision-making, thereby increasing the efficacy of conservation planning (Davies et al. 2013, Meffe et al. 2002). Adding the spatial capability of geographic information systems (GIS) offers a practical way to combine geographical data at multiple scales to produce spatially explicit data for use in decision-making (Malczewsky 2006). Although data are available on the relative abundance and distribution of grassland birds for some areas, the information is often too sparse to be used in a reserve design framework. By contrast, habitat data and management information are more readily obtainable from a geospatial dataset or using remote sensing.

Patch-level factors such as area, shape, and isolation are known to affect wildlife populations. Grassland birds tend to favor large grassland patches and avoid smaller fragments and patch edges (Helzer and Jelinski 1999, Herkert 1994, Keyel at al. 2013, Vickery et al. 1994, Walk and Warner 1999). Landscape-level factors such as roads, forests, agriculture, and urban development have also been shown to have important negative effects on grassland bird population viability (Bakker et al. 2002, Ribic and Sample 2001, Rodewald 2003). Additionally, the selection of priority conservation areas should not solely rely on habitat and biological information related to the target species, but should also account for the feasibility of implementing management practices (Knight and Cowling 2007). Thus, successful plan implementation requires the inclusion of characteristics that directly affect the probability of conservation, such as current management objectives and level of protection. Because the relative importance of these factors is unknown, MCDA provides a framework for assessing the sensitivity of grassland patches to a diverse set of criteria.

The identification and conservation of high-quality habitat for grassland birds and the implementation of bird-friendly management in agricultural landscapes is essential to reverse negative population trends of grassland birds and to conserve grassland bird biodiversity. We used the Champlain Valley of Vermont as a case study to test the efficacy of MCDA to select priority areas for species conservation in human-dominated landscapes. Similar frameworks have been used by geologists, engineers, and land-use planners for site selection for landfills (Sener et al. 2006), and for the identification of areas vulnerable to contaminants (Lowry et al. 1995), but we are aware of only one other study in which this framework has been used to address a conservation issue (Phua and Minowa 2005).

Methods

Study area

The Champlain Valley (CV) is a 600,000-ha region in northeastern North America surrounding Lake Champlain in Vermont and New York, and Quebec, Canada. We worked in the Vermont portion of the CV. The land use/land cover of the CV is 26% agriculture, 50% forest, 9% urban, 13% lakes and rivers, and 2% wetlands (Troy et al. 2007). The CV has a relatively large amount of potential habitat for grassland birds (130,000 ha including over 32,500 grassland patches) and is situated in the Lower Great Lakes/St. Lawrence plain physiographic Bird Conservation Region, which supports some of the largest populations of grassland birds in eastern North America. These factors have led to grassland birds being targeted as a conservation priority in the region (Jones et al. 2001, Rich et al. 2004).

Criteria and GIS analysis

The basis for our analysis was a vector layer that included all grassland patches in the CV. This layer was derived from the United States Department of Agriculture Common Land Unit boundaries data obtained from the Farm Service Agency

(2008) and corrected using visual interpretation of remotely sensed imagery. These patches are actively managed for agricultural production and represent permanent, contiguous boundaries of fields with common land cover, management, and ownership. All remaining grasslands were hand digitized from National Agriculture Imagery Program (NAIP) orthophotographs. The Common Land Unit patches used in this study were categorized as crop fields (corn, hay, other crops, or fallow), and the hand-digitized patches were categorized as suburban/pasture (agricultural pastures or large non-agricultural "suburban" fields).

We used patch-level and landscape-level components to rank grassland patches for their importance to grassland birds. Within the patch-level component, we identified 4 criteria: patch size, perimeter-to-area ratio, management intensity, and conservation status. As grassland birds exhibit edge avoidance in nest placement (Keyel et al. 2013, Perkins et al. 2013), patch size and perimeter-to-area ratio are important attributes in assessing patch quality. Although area and perimeter-to-area ratio values are correlated, we tested their effects independently on outcomes of patch rankings. We considered conservation status and management intensity as human-perceived criteria. Conservation status of the grassland patch addresses threats from incompatible land uses (e.g., potential for development) where the application of bird-friendly management may be less feasible. We assessed the conservation status of each patch with a pre-existing protected-areas layer produced by the Spatial Analysis Laboratory at the University of Vermont (VCGI 2008). This layer included public and private parcels enrolled in any kind of conservation program. Although parcels enrolled in conservation programs may not necessarily equate to long-term protection, we assumed that landowners enrolling their property in any conservation program would increase the probability for greater environmental stewardship. We interpolated the conserved status layer with the grassland patch layers to obtain a ranked value for each grassland patch on the basis of the proportion of their area included in already protected areas. For management intensity, we assigned a value of 1 to suburban/pasture patches because these areas are managed less intensively. By contrast, all other agricultural patches were assigned a score of 0 because these patches are in row crops (primarily corn) or are grass hayfields or alfalfa hayfields that are cut 2–3 times during the nesting season (A. Strong, unpubl. data). In the analysis, we maintained non-grassland agricultural patches because they are often under crop-rotation management and could, at different times, become high quality habitats for grassland birds. These patches also contribute to the openness of the landscape (Keyel et al. 2013) and affect grassland bird settlement patterns (Shustack et al. 2010).

For landscape components, we used 4 attributes: forest, grassland, development, and roads. We used National Land Cover Database (NLCD) tree canopy and impervious surfaces layers (Homer et al. 2004) and our grassland layer to generate maps in which grassland patches were scaled on the basis of the amount of forest, grassland, or developed habitat that was present within a 3000-m buffer around each patch. The choice of a 3000-m buffer was based on landscape-scale effects on habitat selection by *Dolichonyx oryzivorus* (L.) (Bobolink; Shustack et al. 2010), and breeding and natal dispersal distances of Bobolinks and *Passerculus sandwichensis* (J.F. Gmelin) (Savannah Sparrow) in the Champlain Valley. For both species, >90% of dispersal events were within 3000 m from their nest site (Cava et al. 2016, Fajardo et al. 2009). More grassland in the landscape increased a patches' criteria score, whereas patches with more forest and urban cover received lower scores. We also categorized grassland patches on the basis of their distance from roads centerlines (Vermont Center for Geographic Information 2009); we assigned a value of 1 for patches >1200 m from highly trafficked roads (traffic volume of ≥30,000 vehicles/day), a value of 0 for patches 0–700 m from highly trafficked roads, and (scaled) intermediate values for patches in between these distances (Forman et al. 2002). We used a neighborhood analysis to summarize landscape values at the raster level, and transferred the information to each patch using ArcGIS's zonal statistics.

Once quantitative scores for each criterion were generated, we standardized them using a linear scalar transformation so all scores could be compared on a scale from 0 to 1 (Malczewsky 1999). Consequently, each grassland patch had a numerical score ranging from 0 (low quality) to 1 (high quality) for each of the 4 landscape criteria and each of the 4 patch criteria. Because the factors that we quantified included criteria at 2 spatial scales and factors (such as conservation status) that may not affect grassland bird settlement decisions, we used 2 approaches to incorporate this information into our prioritization of conservation decisions. First, we created a set of 36 scenarios by varying the relative importance (i.e., weight) associated with each of the attributes. This allowed us to quantify the effects of variation in landscape-level vs. patch-level attributes, as well as vary the weights associated with each of the criteria at both spatial scales. Second, we used the results from each of the 36 scenarios to conduct a sensitivity analysis to quantify how robust each patch was to variation in weighting schemes. Thus, we used variation in weights across all of the scenarios to assess how each criterion affected the determination of patch quality for grassland bird management.

The 36 scenarios that we assessed varied in the relative importance (i.e., weights) applied to the landscape-level and patch-level components and among the criteria within these 2 components (Table 1). These diverse scenarios allowed a wide spectrum of possible outcomes. We altered the weights within the landscape-level and patch-level components based on a literature review (as outlined in the preceding section) and a survey administered to 7 grassland bird experts knowledgeable of the study region. We structured the survey such that each criterion was compared to all others within the same component (patch or landscape) using the pairwise-comparison method (Saaty 1980). For this "expert scenario", we used the survey results to decide criterion weights, whereas for all the other scenarios, the weights were determined by interpreting the literature. We calculated a consistency ratio (here, our consistency ratio was <0.09, indicating moderate consistency), suggesting that the comparisons used to calculate the weights were consistent within the expert scenarios (Malczewsky 1999, Saaty 1980).

Table 1. Variation in weights used in the 36 scenarios evaluated. [Table continued on next page.]

	Description	Weighting coefficient	
Component-level strategies			
ME	Landscape component equal to patch component	Landscape	0.50
		Patch	0.50
		Sum	1.00
ML	Landscape component more important than patch component	Landscape	0.75
		Patch	0.25
		Sum	1.00
MP	Patch component more important than landscape component	Landscape	0.25
		Patch	0.75
		Sum	1.00
Criteria-level strategies–LANDSCAPE component			
EQUAL (LAND1)	All criteria proportionally equal	Grassland	0.25
		Forest	0.25
		Development	0.25
		Roads	0.25
		Sum	1.00
OPEN (LAND2)	Openness of the landscape is prioritized	Grassland	0.48
		Forest	0.11
		Development	0.11
		Roads	0.30
		Sum	1.00
EXPERT (LAND3)	Expert opinion that prioritizes grasslands over other criteria	Grassland	0.62
		Forest	0.20
		Development	0.11
		Roads	0.07
		Sum	1.00

Table 1, continued.

	Description	Weighting coefficient	
Criteria-level strategies–PATCH component			
MANAGEMENT (PATCH1)	Management criteria is prioritized	Area	0.31
		Management	0.58
		Conserved	0.11
		Sum	1.00
EXPERT2 (PATCH2)	Expert opinion that prioritizes area over all other criteria	Area	0.69
		Management	0.24
		Conserved	0.07
		Sum	1.00
MANAGEMENT_R (PATCH3)	Management is prioritized and perimeter-to-area ratio is used instead of area criteria	Perimeter/area	0.31
		Management	0.58
		Conserved	0.11
		Sum	1.00
EXPERT2_R (PATCH4)	Expert opinion that prioritizes area over all other criteria (perimeter/area ratio used instead of area)	Perimeter/area	0.69
		Management	0.24
		Conserved	0.07
		Sum	1.00

Quality scores

We used variation in weights at the component (landscape-level or patch-level) and criteria level (grassland, development, forest and road within landscape; patch size, perimeter-to-area, management, and conservation status within patch) to create quality scores for each patch across each of the 36 scenarios. The quality scores were calculated by multiplying the patch's score for each criterion by its scenario-specific weight (Fig. 1); specifically, quality scores were the result of the multiplication of weights by criteria within each component (component value = $\Sigma w_i x_i$, where x_i is the score for each parcel for the ith criterion and w_i is the weight for that criterion [$\Sigma w_i = 1$ and $0 \leq w_i \leq 1$]) and then summing the result of the multiplication of weights by components (patch value = Σw_jLandscape + Σw_jPatch, where w_j is the weight for each component and landscape and patch are the component values [$\Sigma w_j = 1$ and $0 \leq w_j \leq 1$]) (Malczewsky 1999). Quality scores for each patch ranged from 0 to 1, and each patch received 36 quality scores, one for each scenario.

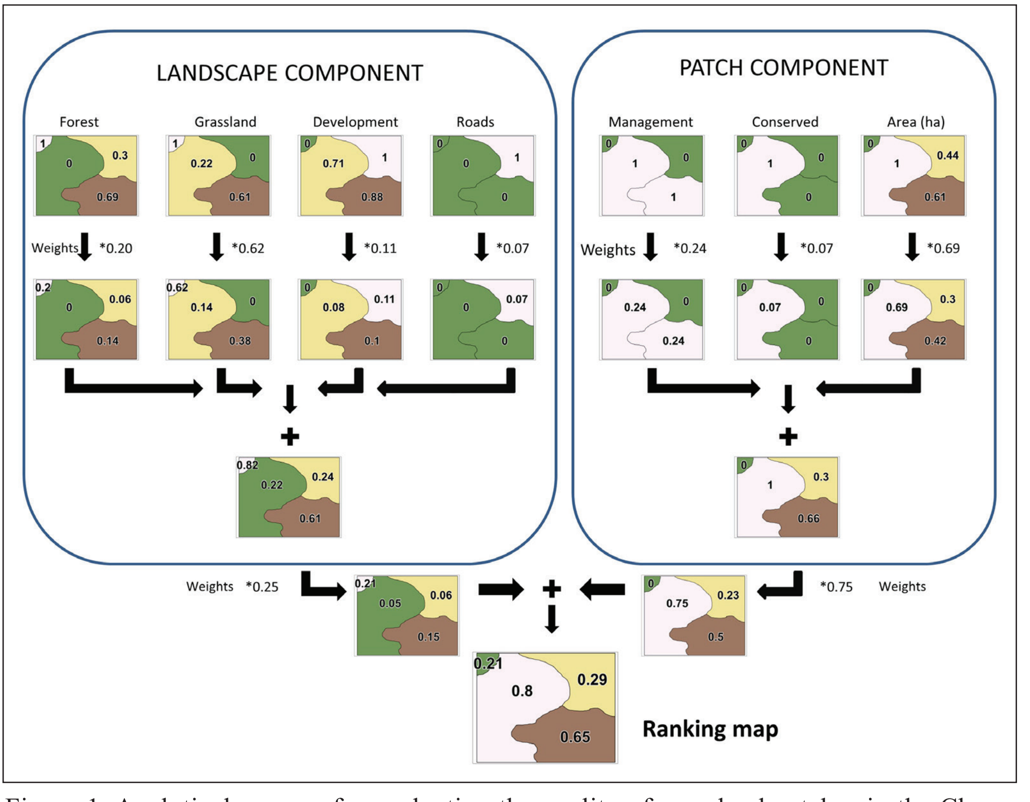

Figure 1. Analytical process for evaluating the quality of grassland patches in the Champlain Valley of Vermont. The scenario illustrated above is one in which the patch component is weighted more heavily than the landscape component (MP in Table 1). Within the patch-level component, the greatest weight is given to patch area criterion (PATCH2), and within the landscape-level component, the greatest weight is given to the proportion of grassland habitat within 3000 m of the patch (LAND 3).

Sensitivity analysis

Using the results from the 36 scenarios, we ranked each grassland patch for inclusion in priority conservation areas. We identified 5 quality classes: "very low" (values $0 \leq x < 0.2$), "low" (values $0.2 \leq x < 0.4$), "medium" (values $0.4 \leq x < 0.6$), "high" (values $0.6 \leq x < 0.8$), and "very high" (values $0.8 \leq x \leq 1$). We assessed the robustness of patches for grassland bird conservation based on their frequency of occurrence in the high and very high quality categories across all scenarios. We classified patches that scored high or very high in ≥18 of the 36 scenarios, regardless of the weights attributed to criteria and components, as "good" patches. Patches that scored high or very high in 9–18 of the 36 scenarios were classified as "intermediate", and patches that scored high or very high in <9 of the 36 scenarios were classified as "poor". By assessing the degree to which each patch was robust to the criteria at the 2 scales, we removed some of the arbitrariness in the prioritization scheme.

We used the kappa index of agreement (Landis and Koch 1977) to compare among scenarios and 2 "null scenarios" in which all weights were kept equal. This test statistic (Cohen's Kappa) is used to evaluate inter-rater reliability and was adapted for pair-wise comparisons of scenarios to determine the influence of weights applied to components or criteria. Kappa values ≤ 0 indicate no agreement, whereas values of 1 constitute perfect agreement.

Priority conservation areas identification

The output from the sensitivity analysis identified a robust set of individual grassland patches for conservation; however, we wanted to identify patches in a block or area to prioritize for outreach, conservation, and management. Several methods can be used to select priority blocks, especially when considering the many constraints that managers must address (e.g., willingness of owners to be involved in some kind of management, pecuniary availability for purchase/protection of particularly important areas, and/or connectivity to other patches). We used Boolean operations in ArcGIS to identify 4 conservation scenarios. These examples consider the need for blocks of grassland patches >100 ha to obtain greater species richness. We applied thresholds to first aggregate good priority patches <10 m from one another, and then aggregated both good and intermediate priority patches <10 m from one another. We subsequently used these 2 thresholds to identify blocks of patches >100 ha that could support breeding by grassland birds species known to require large grassland patches in the northeastern United States (e.g., *Bartramia longicauda* (Bechstein) [Upland Sandpiper]; Vickery et al. 1994).

Results

Across all scenarios, 23% of all patches (7538 of 32,724) scored high or very high in ≥18 of the 36 scenarios and were therefore classified as good patches. Incremental changes in the priority threshold between 13 and 23 showed 1.3–4.4% changes in the total number of patches retained in the good category (Fig. 2A). Thus, although 18 was chosen as a threshold arbitrarily, incremental changes in the threshold value had relatively minor effects on the number of priority grassland patches, suggesting that overall, the classification scheme was insensitive to changes in category ranges. We used Kappa index of agreement to compare the 36 scenarios from our model to 2 null scenarios. Scenarios that gave greater weights to the patch-level criteria at the component level resulted in greater variation in the total area in each quality class, and therefore decreased Kappa values (Fig. 2B). By contrast, the total area in each quality class was more robust to changes in weights within landscape-level criteria (Fig. 3B, C), and sensitive to changes in weights at the patch (Fig. 3A) and component level (Fig. 3D, E). We compared each scenario to every other scenario to assess congruence of ranking for each grassland patch; low-, medium-, and high-value quality patches showed less congruence in ranking. Very high quality and very low quality grassland patches scored consistently high and low scores across all criteria, respectively, and were less sensitive to changes in weights.

Using the perimeter-to-area ratio as opposed to patch area criterion shifted the patch quality toward higher values (Fig. 2C). Furthermore, greater weighting of the management intensity criterion was influential in increasing patch values. All grassland patches that were part of the suburban pasture layer received a value of 1 for the criterion management (average quality value for these patches was 0.595, versus 0.438 for intensively managed grassland patches; $F_{(1,32722)} = 24{,}511.59$; $P < 0.0001$). This high criterion score combined with its high weight in the (patch-level) management strategy led to higher quality values in scenarios that included this strategy.

Our model classified 7538 out of 32,724 grassland patches as good (less sensitive to variation in component and criteria weights), with habitat characteristics attractive to grassland birds and greater potential to be enrolled in conservation programs, totaling an area of ~33,600 ha (26% of the total grassland area). The good grassland patches identified in the priority map (Fig. 4) were located predominately in the southwestern portion of the study area, with a smaller block of good priority patches present in the northwestern section of the map where agricultural activities are more prominent.

The 4 examples of conservation blocks that we identified (Fig. 5) are one of the multiple ways in which the GIS results can be used by managers to identify priority

Figure 2 (following page). Results of the sensitivity analysis. (A) Cumulative percent frequency of number of patches that were included in the "good" category (>18) across all 36 scenarios. (B) Effect of component weights on congruence between scenarios using Kappa index of agreement (+ 1 SE). Scenario labels are explained in Table 1. Greater weight in the patch component reduces the congruence between pair-wise comparisons of the 36 scenarios with the null scenarios; (C) Averages of scenarios' quality scores by patch-level component strategies showing the effect of the weighting scheme. Scenarios in which management had greater weight and perimeter-to-area ratio criterion was used instead of patch area led to significantly greater quality scores ($F_{3,32} = 22.29$, $P < 0.0001$, $n = 9$) than the expert strategies. See Table 1 for a description of the strategies and the weighting scheme. Each box plot represents minimum, first quartile, median, third quartile, and maximum value of the scenarios quality score average within each component strategy.

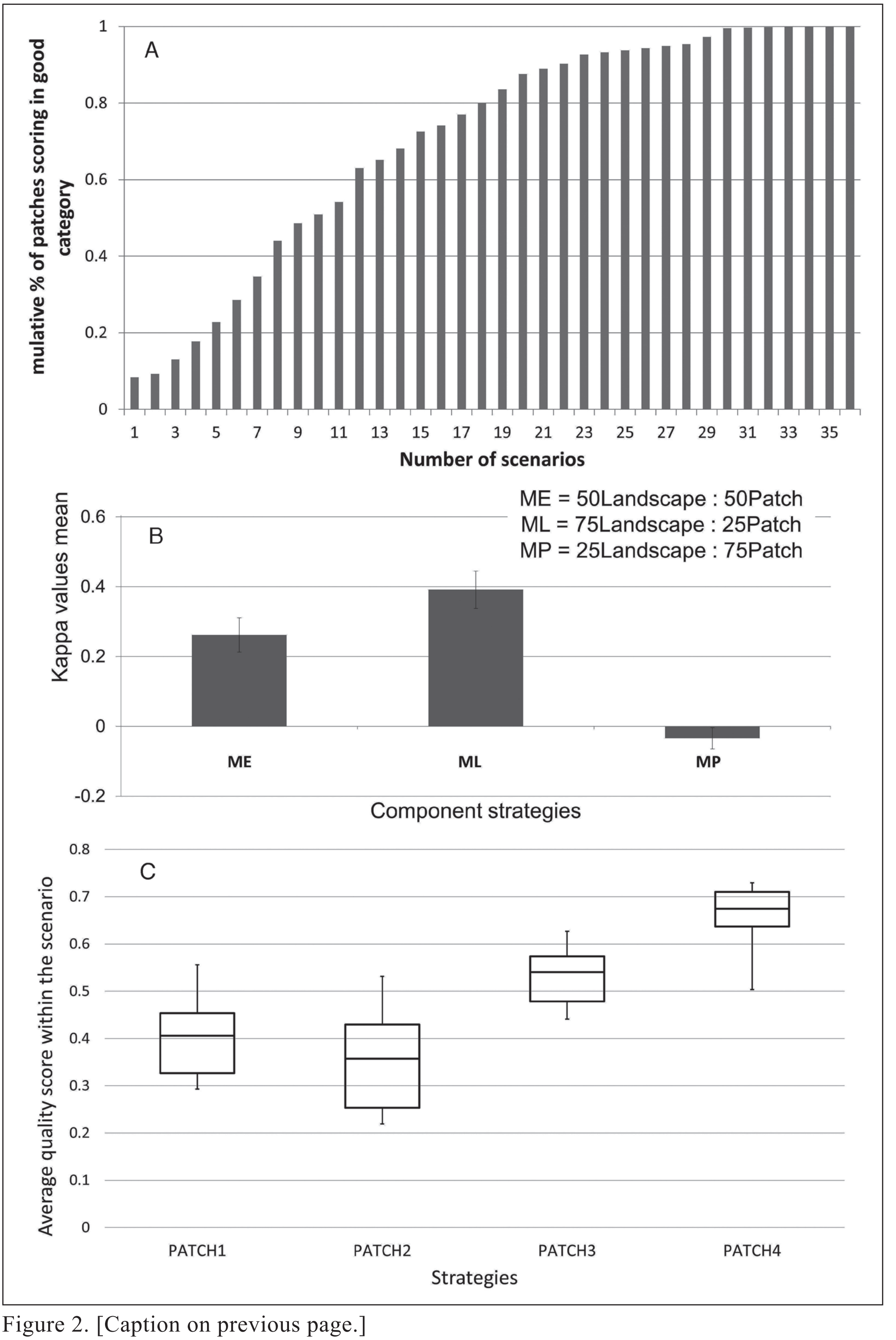

Figure 2. [Caption on previous page.]

conservation blocks. By aggregating patches <10 m from one another, we generated 34 to 114 priority conservation blocks >100 ha, and 17 to 53 of priority conservation areas >200 ha.

Discussion

We combined GIS and MCDA to identify 2 key regions in which to focus conservation efforts for grassland birds in the CV. In this framework, theoretical

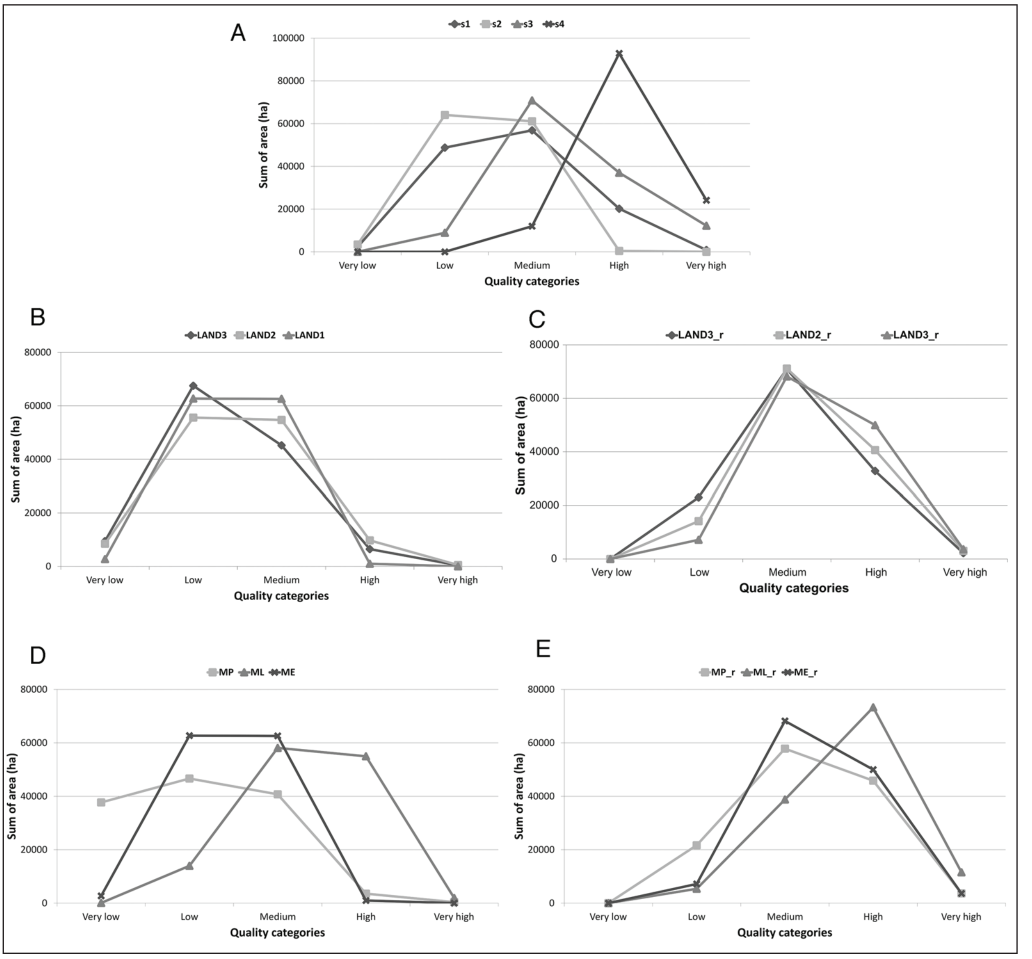

Figure 3. Results of the sensitivity analysis assessing the effect of variation in weights at different levels on the total sum area of patches (ha) in the 5 quality categories and controlling for all other effects: (A) substantial variation between scenarios due exclusively to patch-level weights differences (scenario labels are explained in Table 1: s1 = LAND1 - PATCH1, s2 = LAND1 - PATCH2, s3 = LAND1 - PATCH3, s4 = LAND1 - PATCH4); (B) limited effect of variation in landscape level weights (area criterion used); (C) same as (B) but ratio perimeter-area criterion used; note the change in the shape of the curve; (D) moderate effect of variation in component level weights (ME = equal weights, ML = greater weight to landscape component, MP = greater weight to patch component, area criterion used for each); and (E) same as (D) but perimeter-to-area ratio criterion used.

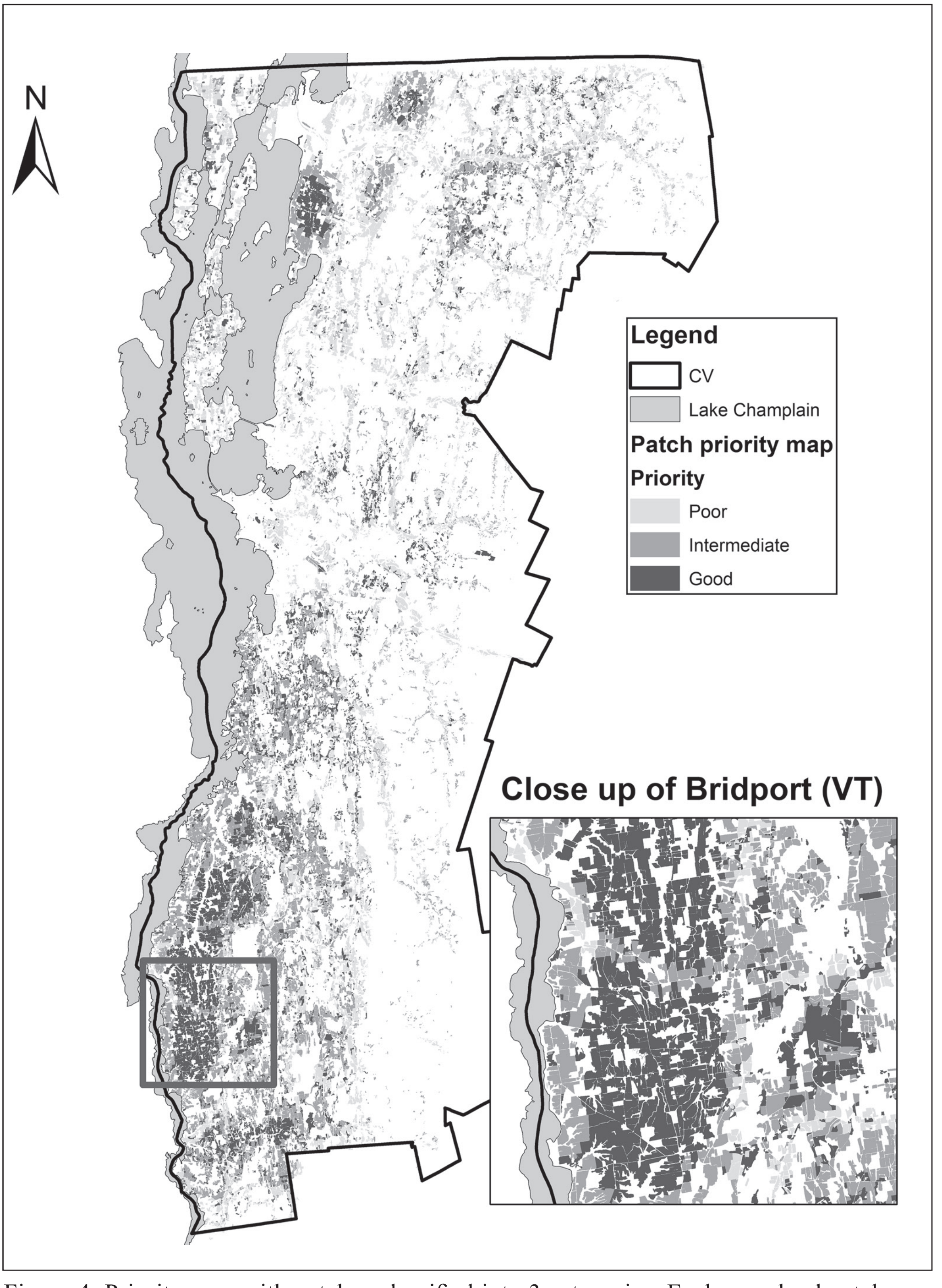

Figure 4. Priority map with patches classified into 3 categories. Each grassland patch was categorized as either poor (scored in the high or very high categories <9 times across all 36 scenarios), intermediate (9–17 high or very high scores) or good (>18 high or very high scores). The inset shows the town of Bridport to better illustrate patch quality variation at a fine scale.

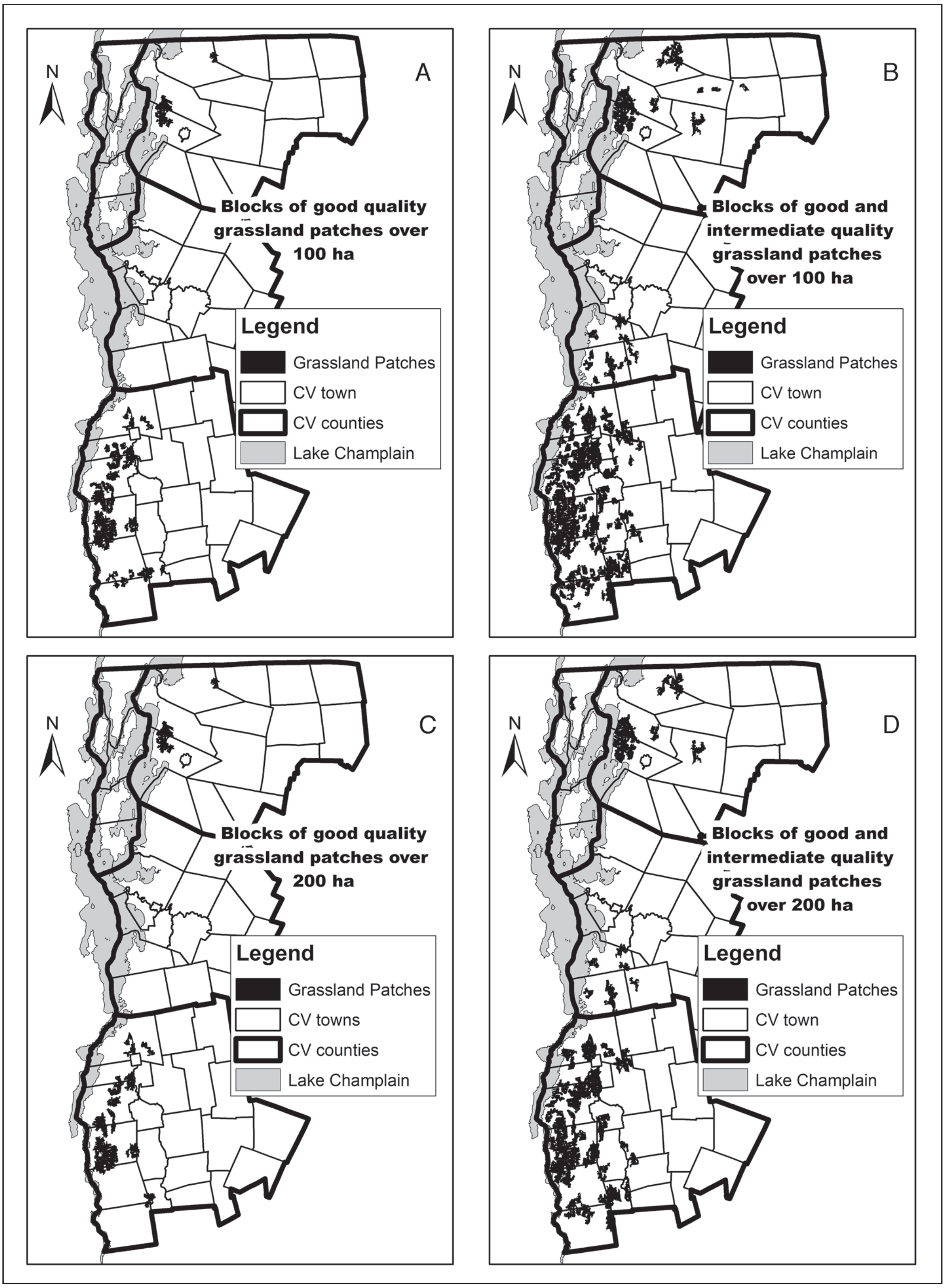

Figure 5. Four examples of priority conservation areas for grassland birds obtained from the priority map. In each map, patches separated by <10 m were aggregated. (A) Good patches aggregated to create patches >100 ha. (B) Good and intermediate patches aggregated to create patches >100 ha. (C) Good patches aggregated to create patches >200 ha. (D) Good and intermediate patches aggregated to create patches >200 ha.

reserve design techniques and management constraints were combined to prioritize conservation and outreach activities. This approach integrated both landscape- and patch-level attributes, and by tailoring the criteria to the species and habitats of interest, it provided a practical framework for prioritizing conservation decisions across our study region and can be applied to other regions or suite of species.

The maps we created used 8 criteria that incorporated both attributes of the site as perceived by grassland birds, and anthropogenic characteristics. These criteria offered the advantages of being easy to obtain or generate, applicable at the chosen spatial scale, and easily modified to extract the desired data. The criteria provided a robust assessment of patch quality, with both very high quality and very low quality patches being insensitive to variation in weighting schemes. Consequently, the priority conservation maps will allow managers to focus on a set of patches that can provide benefits for grassland birds and will have a greater likelihood of being enrolled in conservation programs. Patches with intermediate quality scores (low-, medium-, and high-quality classes) were more affected by variation in weights because their scores varied across criteria and their rankings were not as extreme as for the patches identified as very high or very low quality (Geneletti and Van Duren 2008). Assessing how variation in weights affected patch quality scores is important for understanding model sensitivity. For example, certain criteria had greater impact in driving the characterization of good patches. Patches with a quality score of 1 in the management criterion (32% of the total number of patches) generally received greater scores in many scenarios; 51% of the patches that scored a 1 for the management criterion were classified as good. The conservation criteria could have had a similar effect as management, being almost a dichotomous categorical criterion (with only 10% of the patches having quality scores between 0 and 1). However, ~83% of the grassland patches were not included in conserved areas and received a quality score of 0. Another criterion that contributed in shifting values toward higher quality scores was the perimeter-to-area ratio. In the scenarios in which we used the area criterion, most grassland patches received a fairly low value (many patches in the CV are small with a few outliers). On the other hand, most grassland patches received a high score when we used the perimeter-to-area criterion because most agricultural patches are roughly square or rectangular. Consequently, even small patches may receive high scores when the perimeter-to-area ratio is standardized. Although the definition of a "patch" for a grassland bird is ambiguous, one might consider a size threshold before applying a perimeter-to-area criterion. We advise researchers to evaluate carefully the effect of each criterion in driving the quality value of each patch. Particular attention should be used for dichotomous criteria, such as management and the effect of standardization if the distribution is skewed. The decreased Kappa scores associated with greater weighting on the patch component was likely a result of incorporating 2 dichotomous criteria.

While our analysis was not comprehensive, it provided a streamlined starting point for management planning that is more likely to be applicable than one that is over-parameterized (Malczewsky 1999). For the sake of practicality, parsimony, and simplicity of the model, the criteria were not exhaustive in including all factors that are known to influence grassland bird habitat selection or probability of conservation. However, additional factors could be easily incorporated into the analysis. For example, information on soil, vegetation, inter- and intraspecific interactions, current management regimes, and socio-economic factors connected with agricultural activities are variables that may influence the habitat selection decisions of grassland birds. Further, quality values for cost of patch acquisition, level of involvement of each landowner, and perceived stakeholder value for each patch, once available, could all be included to add a socio-economic component to the analysis.

To minimize the potential arbitrary nature of some criteria scores (Game et al. 2013), we used past studies to generate the criteria incorporated and assessed a wide range of weighting schemes in addressing sensitivity across criteria. We did not correlate these criteria directly with grassland bird density or reproductive success. Instead, the goal of our study was to produce a map showing the greatest potential for cost- and time-effective investment in grassland bird conservation. For example, although grassland birds are significantly more likely to settle in large patches, hayfields that are cut 2–3 times in the growing season will have no Bobolink and limited Savannah Sparrow reproductive success (Perlut et al. 2008). Thus, a large, intensively managed field does provide potential habitat, but was penalized for the low probability of incorporating bird-friendly management practices. As a result, these fields would not be prioritized in outreach activities.

Other advantages of this approach

The involvement of experts in the selection of criteria and their weights can improve the quality of the final results (Geneletti and Van Duren 2008). We involved grassland bird experts in the selection of the criteria to include in our model, asking them to compare pairs of criteria and decide which of the 2 was more important. Scenario s12, in which both landscape and patch weights were determined with the help of the experts, provided the highest Kappa value when component weights were equal. This result supports the involvement of experts starting early on in the process of criteria selection. The same methodology could be used as new criteria become available, enlarging the panel of experts or opening it to additional stakeholders to offer further perspectives in the decision process (Geneletti 2007).

Although more spatial datasets are available in raster format, the vector dataset used here provided several advantages. Utilizing a vector-based spatial dataset, combined with information on the management of grassland parcels, provided a more precise delineation of the grassland patches with up-to-date information on management practices. Such precision cannot be obtained using a raster-based approach. The advantages of using parcel-based maps included ease of tracking changes in patch shape and simplicity of joining additional information to the spatial dataset for statistical analyses.

Limiting our analysis to grassland patches also provided some advantages over other approaches. In many reserve-design scenarios, constraints are used to exclude unsuitable habitat from the analysis (Carrion et al. 2008, Malczewsky 1999, Sener 2004). Because only potential habitat was included in the spatial dataset, we excluded constraints from the analysis, thereby simplifying the analytical process. Cost criteria, included in our analysis, were standardized using a "reverse" formula that gave lesser values to the patches that have greater costs for the criterion analyzed. Patches with standardized values of zero for certain criteria were not automatically excluded as unsuitable patches as done by using a constraints framework, but a zero value contributed to lowering the overall quality score of a given patch. This process can also be used to rank focal conservation areas both on the basis of their quality for the species considered and for their potential for cost- and management-effective initiatives.

Reserve maps produced using Boolean selection operations provided one means to visually summarize the delineation of a reserve system. We based the selection process of priority conservation areas on threshold sizes of 100 and 200 ha as suggested by Vickery et al. (1994). These large blocks (for the northeastern US) were also chosen considering that the size of a reserve is correlated to the number of species that it can support (Diamond 1975), and the fact that most grassland species are area sensitive and some, in particular the Upland Sandpiper, require large continuous grasslands (Houston and Bowen 2001). The priority conservation areas (Fig. 5) depicts a robust system of high quality habitat distributed in the southern portion of the study area where most of the agriculture in the CV is located. If grassland birds are distributed as a metapopulation, this spatial arrangement of blocks should allow exchange of individuals between patches. Generation of reserve maps offers a versatile way for researchers to apply thresholds, incorporate information at different scales than the one used for criteria maps, or include raster-level data that cannot be easily summarized in a vector-based format.

The integration of MCDA and GIS is a valuable framework for prioritizing conservation and management decisions. The maps should be considered as the "foundation" on which the conservation of grassland birds can be built. Managers and stakeholders can apply this tool to help guide outreach for promoting conservation and alternative management practices where they should have the greatest chance of success. The methods used to generate the priority maps and the tools created in ArcGIS can be thought of as "blue prints" that can be copied as is or modified for specific needs in identifying priority conservation areas. The versatility of MCDA and the spatial capability of the methodology applied in this study to identify priority conservation areas for grassland birds can be easily modified to address specific needs for different species, guilds, taxa, communities, and/or locations. Diverse stakeholders can be involved in the decision process. Priority maps, resulting from the multicriteria decision analysis can be used for designing reserves and planning at broad spatial scales. Because resources for conservation activities will always be limited, methodologies for increasing the efficiency of conservation work will always be necessary.

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