Environmental Management (2007) 40:981–992
DOI 10.1007/s00267-007-9025-y

Habitat Acquisition Strategies for Grassland Birds in an Urbanizing Landscape

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Published online: 5 October 2007
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Abstract Habitat protection for grassland birds is an important component of open space land acquisition in suburban Chicago. We use optimization decision models to develop recommendations for land protection and analyze tradeoffs between alternative goals. One goal is to acquire (and restore if necessary) as much grassland habitat as possible for a given budget. Because a viable habitat for grassland birds consists of a relatively large core area with additional parcels of grassland habitat nearby, the second goal is to minimize total pairwise distance between newly protected parcels and large existing reserves. We also use the concept of an effective grassland habitat area, which considers influences that neighboring land covers have on grassland habitat suitability. We analyze how the parcels selected for protection change as total protected effective area is traded off against total distance. As area is weighted more heavily, the selected parcels are scattered and unconnected. As total distance is weighted more heavily, the selected parcels coalesce around core reserves but protect less area. The differences in selected parcels as we change the objective function weights are caused by the differences in price per unit of effective habitat area across parcels. Parcels located in close proximity to the existing cores have relatively high prices per hectare of effective grassland area as a consequence of high restoration costs and adverse influences from roads, urban areas and/or forestland. As a result, these parcels have lower priority for selection when the area objective is weighted more heavily for a given budget.

Keywords Open space · Optimization · Reserve design · Site selection · Urbanization

Introduction

Open space protection in metropolitan areas is commonly used as a policy for regulating landscape change in the United States. Open space reserves, broadly defined as lands not devoted to urban development, are important not only for the protection they afford rare species and ecosystems, but also for the educational and recreational opportunities they provide urban residents (Miller and Hobbs 2002). The Chicago region is a place where county planners are actively pursuing open space acquisition and protection. Current trends suggest that the Chicago metropolitan area will double in size in the next 30 years and consume 500,000 ha of open land. As a result, county Forest Preserve Districts (FPD) in the area have recently garnered nearly $500 million for new land acquisition (Openlands Project 1999). Chicago Wilderness, a partnership of public and private organizations, helps coordinate land protection activities in the region. A central focus of

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the Chicago Wilderness, as noted in their Biodiversity Recovery Plan (http://www.chicagowilderness.org/pubprod/brp/index.cfm), is the acquisition and restoration of native grasslands.

Native grasslands once covered 60% of Illinois, but have been reduced by >99.9% since European settlement (Robertson and others 1997). The loss of grasslands has been pervasive in North America, exceeding that of any other major ecosystem (Samson and Knopf 1994, Noss and others 1995), and this has been a major factor causing grassland birds to experience greater declines than any other behavioral or ecological group of North American birds during the latter half of the 20th century (Knopf 1994, Peterjohn and Sauer 1999). Twenty seven species of grassland birds breed in the Midwestern region and migrate to the southern United States or neotropics in winter, and nearly half of these species are listed as threatened or endangered in at least one state (Herkert and others 1996). Herkert (1991) reports that the most abundant grassland species in Illinois prior to 1900 were the ones that have experienced the most dramatic decreases since. These five species, all grassland obligates, include the Eastern Meadowlark (*Sturnella magna*; -67% change), Dickcissel (*Spiza americana*; -46.7%), Grasshopper Sparrow (*Ammodramus savannarum*; -56% change), Bobolink (*Dolichonyx oryzivorus*; -90.4% change), and Henslow's Sparrow (*Ammodramus henslowii*; too few detections for trend analysis). Whereas bird species associated with wetland and savanna habitats appear to be doing reasonably well as a result of conservation and restoration efforts over the last few decades; trends for grassland species continue to be discouraging (D. Stotz, Chicago Field Museum, personal communication).

Avian conservation has been a major focus of the Chicago Wilderness because of high public interest in birds and the utility of these taxa as indicators of habitat quality (Brawn and Stotz 2001). It follows that the potential benefits conferred to grassland bird species should be a prime consideration among planners and land managers when evaluating different options for expanding existing open space reserve networks.

If a planner had unlimited funds for land acquisition, then it would be relatively straight-forward to design a reserve network that met the needs of grassland-dependent birds. This would be a system that consisted of several large (>600 ha), compact reserves buffered from woodlands, roads, or urban areas with as much grassland habitat in the surrounding landscape as possible (Herkert and others 1996, Bakker and others 2002). However, in reality, acquisition budgets and parcel availability are always limited, and the juxtaposition of land covers may be less than ideal. In this situation, the planner needs to formulate measurable design objectives that are related to the habitat protection recommendations at the local scale. Optimization models offer one approach to help planners formulate management objectives, develop land protection strategies, and identify the trade-offs associated with different protection goals and priorities.

Optimization decision models for reserve site selection have been developed over the past two decades with objectives that account for representation of a diversity of species or other conservation features (see Cabeza and Moilanen 2001, ReVelle and others 2002, and Rodrigues and Gaston 2002 for reviews) or spatial attributes of reserve systems that promote species' persistence (see Williams and others 2005 for a review). Recently, authors are beginning to build reserve site selection models that address species' specific habitat needs and persistence criteria (Hof and Raphael 1997, Hof and others 1999, Van Langeveld and others 2000, Hof and others 2002, Haight and others 2004, Poulin and others 2006, Van Teeffellen and others 2006). We know of only one site-selection optimization model that explicitly addresses land acquisition issues specific to grassland habitat and/or grassland-dependent species (Pykälä and Heikkinen 2005).

This study adds to the body of literature on reserve site selection models that address taxa-specific habitat needs. Important features of our model include the consideration of existing protected areas in the reserve design, habitat restoration as a management option, and the influence of adjacent land cover on habitat quality. Two planning objectives are considered. The first objective of the model is to protect as much grassland habitat as possible within a given budget. The second is to select parcels for acquisition and restoration which promote the compactness of the resulting reserves. The model is formulated as a linear integer program which can be solved quickly using exact solution methods.

Methods

Study Area

Our research focused on Kane County, Illinois, which comprises approximately 136,000 ha on the western fringe of the Chicago metropolitan area (Fig. 1).

Historically, more than half of the county was tallgrass prairie (Kilburn 1957). Kane County's population was estimated at 472,000 in 2004 and is increasing by approximately 11% annually as a result of expansion from Chicago (http://www.nipc.org/forecasting/cnty2004.html). While much of the land here is agricultural, a large portion of the county has been designated as "high risk" in terms of future development (Openlands Project 1999). Urban and suburban land uses afford less in the way of habitat

Fig. 1 Location of Kane County, Illinois, relative to the City of Chicago and the 13 counties in the Chicago Wilderness. The two white circles represent the largest contiguous grasslands currently owned by the Kane County Forest Preserve District, the Dick Young Forest Preserve in the south–central portion of the county and the Burlington Prairie Preserve in the northwest

value for grassland birds than some of the agricultural uses they replace, but urbanization may carry with it opportunities to expand the current reserve network, in the form of a larger tax base and greater support for land protection among voters (Trust for Public Land and Land Trust Alliance 2004). Currently, about 3% of the land area in Kane County is protected open space, and the Forest Preserve District is actively pursuing opportunities to purchase and set aside land for purposes of conservation (Drew Ullberg, Kane County Forest Preserve District, personal communication).

Datasets

We used existing GIS coverages (current as of January 2005) to identify parcels that were potentially available for acquisition. Kane County provided digital parcel data as well as layers depicting primary and secondary roads, and Forest Preserve District Lands. Additional data layers were acquired from Natural Connections: Green Infrastructure (http://www.greenmapping.org), which is affiliated with the Openlands Project in Chicago. These layers included row-crop agriculture, hayfields, pastures, woodlands, residential, commercial, and industrial.

Habitat Protection Strategy

Herkert and others (1996) provide a comprehensive review of the conservation of migratory birds in Midwestern grasslands and develop management recommendations on this basis. Because population declines appear related to the loss and fragmentation of native grasslands (and more recently hayfields and pastures), these recommendations emphasize habitat restoration. Several grassland bird species are area sensitive and avoid small habitat fragments. Herkert and his colleagues (1996) concluded that the minimum area required for >50% likelihood of occurrence is 10–100 ha, and that nest success would be lower in small fragments (<50 ha) than in large fragments (>100 ha). To avoid creating sink habitat (Pulliam 1988, Pulliam and Danielson 1991), Herkert and his colleagues (1996) build in a large safety margin by recommending that regional habitat restoration include some contiguous areas of grassland >600 ha. Recommended actions at local scales included restoring parcels adjacent to existing grasslands to increase the size of contiguous habitat blocks.

Since Herkert and others' (1996) review, several authors have added new survey results and management recommendations. Helzer and Jelinski (1999) and Davis (2004) found that edge-to-area ratio (compactness) of a fragment was a better predictor of incidence than fragment area for some grassland bird species. Bakker and others (2002) found that the presence of a species in a patch may depend not only on local vegetation structure and patch size, but also on the amount of grassland habitat in the surrounding landscape. Whereas one study found that nest predation rates for some species were lower in larger patches (>1000 ha) than smaller patches (<100 ha; Herkert and others 2003), others found that patch or landscape level variables did not affect nest success (Davis and others 2006, Winter and others 2006). While these results highlight differences among regions with different landscape compositions and different predator assemblages, they also underscore the fact that a definitive answer has yet to emerge regarding the value of smaller habitat parcels in different landscapes.

Nonetheless, most of these authors tend to agree that, where possible, a good strategy is to protect and restore large contiguous areas of grassland habitat at regional scales, recognizing that this objective might not be feasible for land managers working at the local (e.g., county) scales. In this latter case, the general recommendation is to focus additional habitat protection in areas surrounding existing grasslands. Johnson and Igl (2001) note that restoring small grassland fragments near existing habitat blocks would benefit more bird species than would small, isolated patches. In addition, the attractiveness of irregular-shaped patches could be enhanced by increasing patch size and minimizing the amount of edge habitat (Helzer and Jelinski 1999, Davis 2004). Others have suggested that small grassland fragments should receive consideration, regardless of their location, as part of conservation networks because at least some grassland bird species do not appear to be area sensitive in some regions (Davis 2004, Davis and others 2006). Further, increasing the overall amount of habitat surrounding existing grassland remnants can enhance the probability of species occurrence for some grassland birds (Bakker and others 2002).

These guidelines for grassland habitat restoration are consistent with theoretical insights obtained from empirical and modeling studies of the effects of habitat amount and configuration on richness and persistence of avian species. In her synthesis of the literature, Fahrig (2002) concluded that overall habitat loss has a much larger effect than habitat fragmentation on the distribution and abundance of birds. She argued that habitat removal causes an increase in the rate of dispersal into the matrix, which decreases reproduction and increases mortality rates of the population at the landscape scale. This contention is further supported by Hanski (2005), who argued that structural connectivity among habitat patches is less of an issue for birds than for organisms with more limited dispersal abilities, assuming that the habitat patches are of sufficient size and quality. The management implications are that alterations in habitat configuration are likely to have only a small effect on avian population persistence and thus emphasis should be placed on increasing the total amount of habitat protected. With and King (2001) formulated a demographic model of avian species in which patch occupancy (%) increased with patch size and fecundity increased with lower patch edge to area ratios. They found that the amount of habitat required for population persistence varied widely (5–90% of the model landscape) depending upon the species' edge sensitivity. They concluded that edge-sensitive species should be managed by preserving large amounts of habitat with maximum clumping. For species with low edge sensitivity, the best strategy is to increase the overall amount of habitat.

To model these grassland habitat restoration guidelines, we created two site selection objectives for use at the county level. Given that the largest block of existing grassland habitat in the county is 94 ha (the Dick Young Forest Preserve: Figs. 1 and 2), attempting to meet the recommendation of a 600-ha block (Herkert and others 1996) seemed unrealistic at the county scale, particularly in light of the fragmented nature of the existing and restorable grassland parcels. Instead, we focused on the two largest contiguous FPD grassland blocks (hereafter, core areas), the Dick Young Forest Preserve in the central section of the county, and Burlington Prairie in the western section with 39 ha of contiguous grassland (Figs. 1 and 2). Given high land costs in the county and limited acquisition funds for open space, we only considered parcels for acquisition that were within a 6-km radius of each of the existing cores. The first objective was to choose parcels for acquisition and restoration to minimize the sum of the distances between parcels selected and the closest preserve. This objective recognizes that protecting and restoring small grassland fragments near existing grassland habitats is preferable (Johnson and Igl 2001). Further, the objective attempts to protect an assemblage of parcels around each core area, thereby increasing the size and compactness of the reserve (Helzer and Jelinski 1999, Davis 2004). The second objective was to maximize the total area of protected grassland parcels without considering their distances from the existing core areas or each other. This objective recognizes that small fragments may also have value to some grassland bird species and landscape structure can be enhanced by increasing the total amount of protected habitat surrounding existing grassland (Davis 2004, Davis and others 2006, Bakker and others 2002).

Habitat Suitability

Parcels classified as residential, commercial, and industrial were reclassified as "urban," and as such, ineligible for acquisition. Given that our focus was on grasslands, parcels

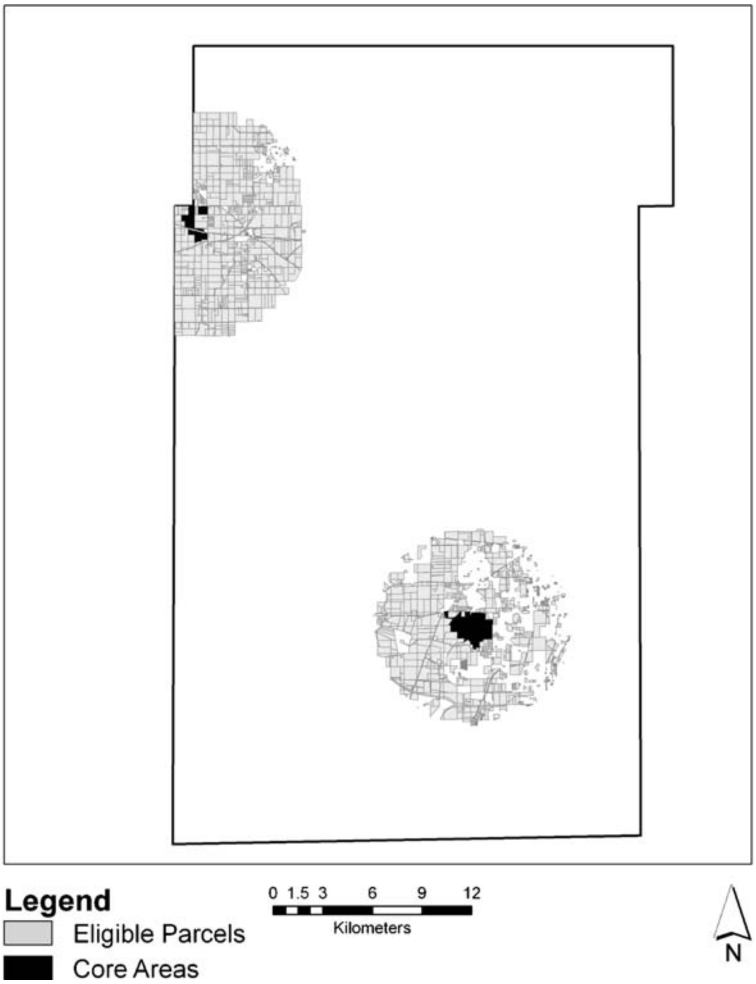

Fig. 2 The two core areas and associated parcels in Kane County, Illinois, that were eligible for acquisition during model runs

that were entirely woodland were also considered unsuitable habitat and as such, ineligible. In addition to remnant, restored, or constructed prairies, these species will use lower quality habitats, such as pastures or hayfields, that largely consist of nonnative grasses. In fact, given the near-elimination of native prairies, such habitats may be the key to the persistence of obligate grassland birds in this region (Herkert and others 1996). Therefore, parcels comprising prairie, hayfields, or pastures were classified as “grassland” and eligible for acquisition. Row crops do not provide habitat for grassland birds (Best and others 1997), but could be restored to a suitable condition. Therefore, parcels with row-crop agriculture were eligible for acquisition, but incurred additional habitat restoration costs as described below (see Acquisition and Restoration Costs).

Some grassland bird species will avoid otherwise suitable habitat, depending on the juxtaposition of other types of land cover or land use. For example, the density of Bobolinks has been shown to increase with distance from wooded edges, but this pattern was not observed in proximity to agricultural fields (Fletcher and Koford 2003). Similarly, Bock and others (1999) found the abundance of grassland obligate species to be substantially lower near housing developments than in more remote areas. Grassland birds were also found to occur in lower abundance near roads (Forman and others 2002). Based on these studies, we conservatively estimated that such effects would extend 50 m into grassland habitats from adjacent roads, urban areas, or woodlands. We therefore considered the effective habitat area, or the area that would likely be used by grassland birds, to be the amount of grassland remaining on a parcel once the area within this 50-m buffer was subtracted from the total amount (Fig. 3). We used the construct of effective habitat area as a means to make land acquisition decisions that considered the influence of neighboring features on the landscape and associated edge effects on grassland habitat suitability.

Acquisition and Restoration Costs

Clearly, the ability to implement any strategy aimed at expanding reserve networks will be highly dependent on the financial costs of doing so. We therefore incorporated

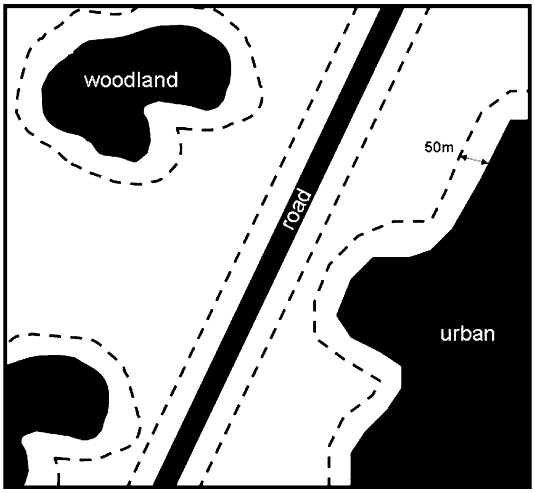

Fig. 3 A conceptual diagram illustrating the way effective habitat area was determined for parcels that were eligible for acquisition during model runs. The white area represents existing or potentially restorable grassland. The dotted lines represent the 50-m buffer applied to urban areas, woodlands, and roads. We considered the areas within these buffers unlikely to be used by grassland bird species and these areas were therefore not included in our calculation of effective habitat area

the costs of acquiring parcels, as well as the costs of grassland restoration, into our decision modeling framework. Acquisition costs were based on estimated market values provided by real estate agents in Kane County. Based on these estimates, we assessed property values in the central section of the county (nearest the urban core) at $98,800/ha and in the western third of the county, which is primarily agricultural, at $24,700/ha.

To our knowledge, restoration costs have not been considered in previous reserve site selection applications. Because grassland birds will nest in nonnative secondary grasslands (Herkert and others 1996) we assumed that parcels classified as "grassland" would not require full-scale restoration. As noted above, parcels comprising row-crop agriculture would require restoration to be suitable for these species. To assign a dollar amount to this process, we consulted two private firms that specialize in prairie restoration in the Midwestern United States and have projects in the Chicago area (Applied Ecological Services, Brodhead, WI; Driftless Area Stewardship, Glenhaven, WI). We averaged estimates that they provided for various components of the restoration process and derived a total cost of $4133/ha for "row-crop" parcels, and $2066/ha for parcels that were a mix of both agriculture and grasslands. Table 1 contains descriptive statistics for eligible parcels in both the central and western sections of the county.

Table 1 Parcels that are potential candidates for acquisition in central and western sections of Kane County, Illinois

	Central tier	Western tier
Number of candidate parcels	1136	768
Total area of candidate parcels (ha)	6096	7355
Total effective area of candidate parcels (ha)*	4177	5911
Largest parcel (ha)	64.4	65
Average parcel size (ha)	5.4	9.6
Number of mixed parcels (row-crop and grassland)	66	80
Number of grassland parcels	544	205
Number of row-crop parcels	526	483
Total area of row-crop parcels (ha)	4135	6058
Total area of grassland parcels (ha)	727	321
Total area of mixed parcels (ha)	309	405

* See Habitat Suitability in the Methods section

Model Description

We developed and solved a two-objective optimization model that maximized effective grassland habitat area and minimized total pairwise distance to established core areas subject to a budget constraint. Note that the distance objective could be viewed as a special case of the reserve site selection objective developed by Önal and Briers (2002) where all pairwise distances are set equal to zero except the distances between eligible parcels and their nearest core area. The model was defined as follows:

Parameters:
w_1 and w_2 are nonnegative objective function weights whose sum equals 1 ($w_2 = (1-w_1)$),
j, J are the index and set of eligible parcels,
B_1 and B_2 are the specified upper and lower bounds on the total cost of acquiring parcels, where total cost includes acquisition and restoration costs,
A_j is the effective habitat area of parcel j (hectares),
C_j is the cost of acquiring and restoring parcel j,
D_j is the straightline shortest distance between the edges of a given parcel and the edge of the nearest existing core reserve (meters),
X_j = {a 0–1 decision variable equal to 1 if parcel j is selected for protection, and 0 otherwise}.

The model was formulated as follows:

$$Maximize Z = (w_1 * (\sum_{j \in J} A_j X_j)) - (w_2 * (\sum_{j \in J} D_j X_j)) \quad (1)$$

Subject To:

$$\sum_{j \in J} C_j X_j \leq B_1 \quad (2)$$

$$\sum_{j \in J} C_j X_j \geq B_2 \qquad (3)$$

$$X_j \in \{0, 1\} \qquad (4)$$

The objective (1) is a statement of the two objectives to maximize total effective grassland habitat area while minimizing total pairwise distance from each parcel to its closest existing protected reserve core. Constraints (2) and (3) together require that the total expenditures on parcel acquisition and restoration be between upper and lower bounds of B_1 and B_2, respectively. Constraint (4) defines the integer restrictions for the decision variable.

Modeling Framework

Our analysis focused on generating trade-offs between total protected effective grassland habitat area and total pairwise distance between newly protected parcels and existing core reserves, a measure of the proximity of protected parcels to the existing cores. We analyzed how the allocation of funds and selection of parcels in the two sections of the county changed as the weights for the two objectives changed. We also compared optimal site selections for strategies in which protection decisions could only be made in the central section of the county versus selections that included both the western and central sections of the county. Given that development is encroaching more rapidly on the central section of the county, there may be a greater urgency to acquire additional open space there. However, we wanted to investigate how a central-section focused selection strategy compared to one in which parcels in the west were also given consideration. The total level of expenditures for all strategies was constrained to be between \$49 million and \$50 million, an approximation of the level of funding that the county has raised for open space acquisition through recent bond initiatives.

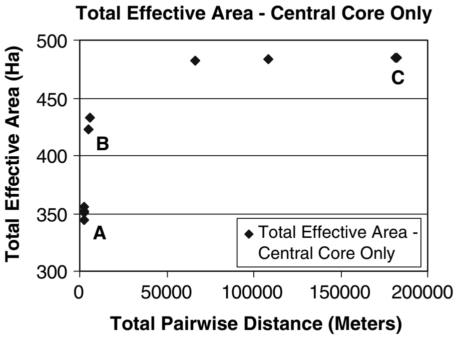

Fig. 4 Trade-off curve for central section selections illustrating a sharp trade-off between total effective grassland habitat area and total pairwise distance of parcels to cores

We solved the two-objective optimization model using the multiobjective weighting method (Cohon 1978). The two objective function weights, w_1 and w_2, were systematically varied between the values of 0 and 1, and the problem resolved for each weight pair to generate an estimate of the trade-off curve between the total effective area protected and the total pairwise distance between each selected parcel and its nearest protected core. As the value of w_1 increased with respect to w_2, more weight was given to the first objective, resulting in higher effective areas and larger total pairwise distances. The opposite finding occurs as the value of w_2 increases relative to w_1.

All of the problems were solved on an IBM Pentium™ 4 personal computer, using the integrated solution package GAMS/CPLEX 9.0 (GAMS, 1990). Solution time was less than a minute for all runs. Input files were created using GAMS (General Algebraic Modeling System), a program designed to generate data files in a standard format that optimization programs can read and process. The models were solved using CPLEX, an optimization solver designed for linear and integer problems. The revised primal simplex algorithm, in conjunction with the branch-and-bound algorithm for integer-variable problems, was used to solve the models.

Results

Trade-Off Curve for Central Section Parcel Selections Only

Figure 4 illustrates the trade-off curve when only parcels in the central section of the county were eligible for protection status. Each point on the trade-off curve represents one feasible, nondominated solution to the problem. A nondominated solution is one in which improvements cannot be made in the value of one of the objective functions without a simultaneous degradation of the other. As the total effective area that can be protected increases, so does the total pairwise distance between the selected parcels and the existing reserve in the central section of the county.

As illustrated by the curve in Fig. 4, the trade-off between total effective area and total pairwise distance is quite sharp in portions of the curve. On the portion of the curve from points A to B, total effective area can be substantially improved for relatively small increases in total pairwise distance. Beyond point B, moving left to right on the curve, little gain in total effective area is achieved for significant increase in pairwise distance. The solutions represented by the segment of the curve between points A and B would be desirable ones to consider. If decision makers are interested in acquiring as much grassland habitat as possible for a given budget, then they must be

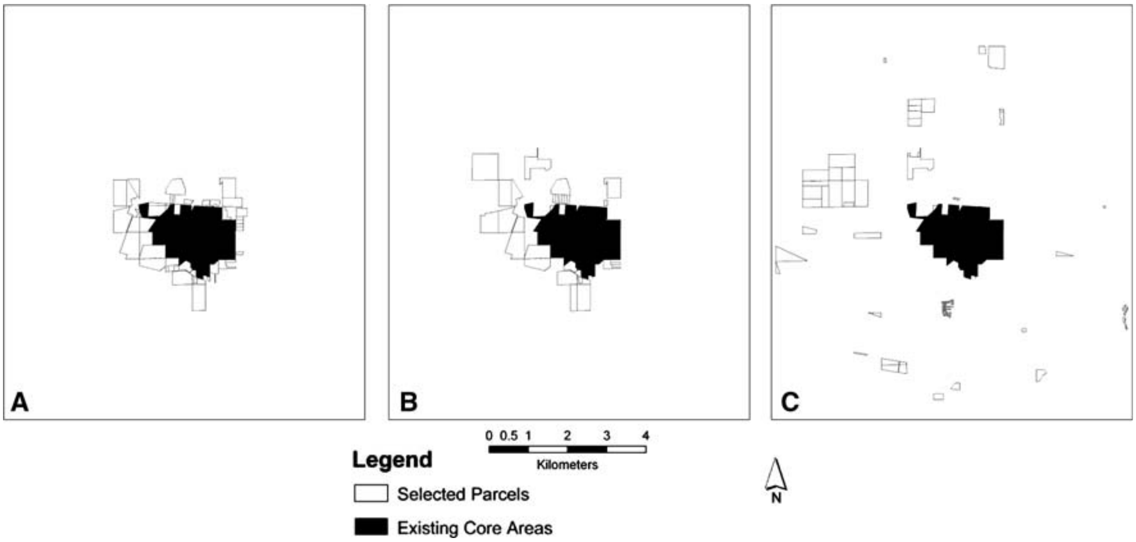

Fig. 5 Three potential solutions for a central section selection strategy. Points A, B, and C correspond to points A, B, and C from Fig. 4. Point A represents a solution which only emphasizes the distance objective. Point C represents a solution which only emphasizes the total effective area solution. Point B represents a solution in which consideration is given to both objectives

willing to accept that the proximity of the set of parcels to the core area will be reduced.

The objective of minimizing total pairwise distance between newly protected parcels and an existing core reserve leads to a compact, almost circular, reserve configuration surrounding the existing core reserve (Fig. 5). In this case, most selected parcels are directly connected to the existing core. This solution results in the selection of parcels with approximately 345 ha of effective habitat. As more weight is placed on the objective of maximizing total effective habitat area, solutions are generated that result in increasing total distances, Solution B (Fig. 5B). At the far right hand side of the trade-off curve, a decision maker could select a set of parcels that would provide the largest total amount of effective area that could be selected for the given budget level, but this comes at the expense of a compact set of parcels, Solution C (Fig. 5C). It is important to note that the set of solutions displayed in Fig. 4 are not an exhaustive set of possible noninferior solutions. Additional solution points may exist along the curve. If specific regions of the trade-off curve are of particular interest to a decision maker, then the multiobjective weighting method and constraint method could be used to generate additional solutions.

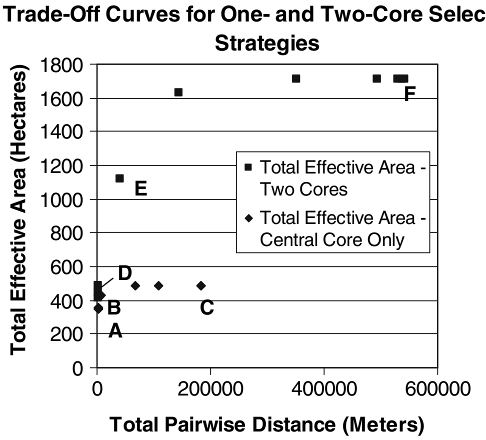

Fig. 6 Trade-off curves comparing Central to Central + Western Section selection strategies illustrating that higher levels of effective habitat area can be acquired for a given budget when an acquisition strategy considers parcels around both cores versus a Central Core strategy only

Trade-Off Curve for Land Acquisition Strategy that Considers Both the Central and Western Sections of the County

Figure 6 contains the trade-off curve for solutions for a strategy in which parcels can be selected in both the central and western sections of the county. Given that land prices in the west are 25% of those in the central section of the county, a land manager is able to acquire a substantially greater amount of effective habitat area by considering parcel acquisition in the west. In Fig. 6, the trade-off curve for the central-only selections is compared to that of a western and central selection strategy. For a given total pairwise distance, a planner is able to protect significantly more effective grassland habitat area by considering western parcels also. The shape of the trade-off curve for the two-core selection strategy is similar to that of the central-core selection strategy. Figure 7 contains the solutions from three points on the curve. Again, when total pairwise

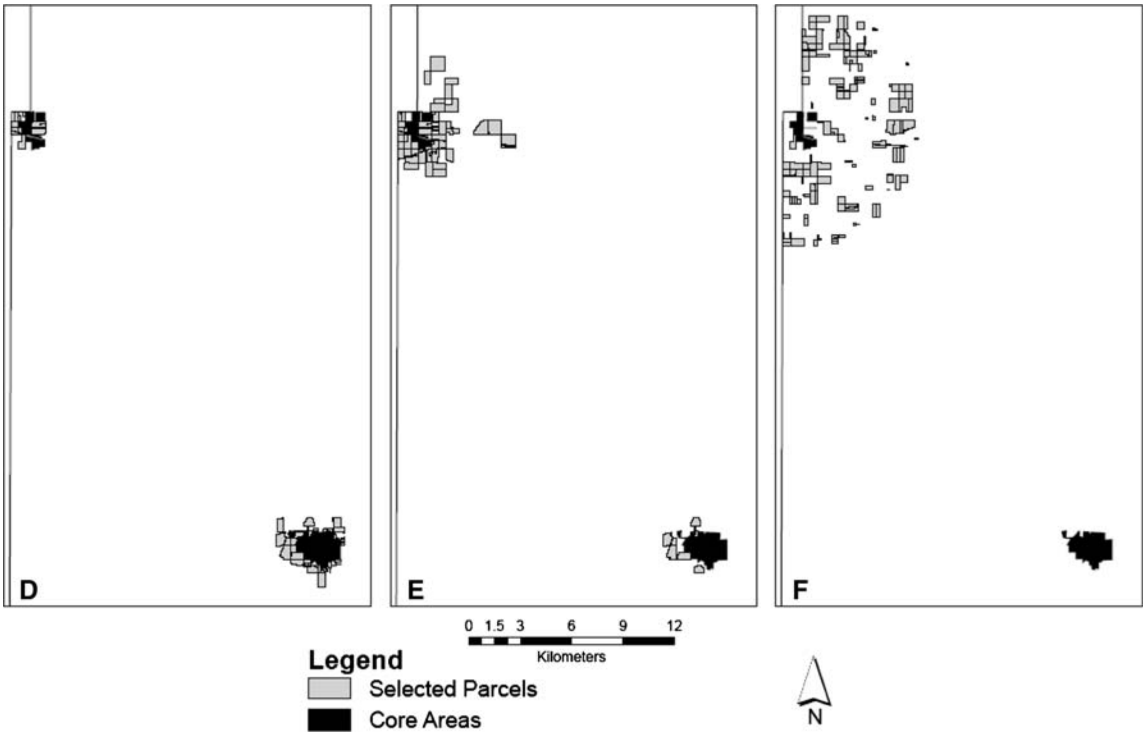

Fig. 7 Three potential solutions for a Central + Western Section selection strategy. Points D, E, and F correspond to the Points in Fig. 6. Point D corresponds to a solution when pairwise distance is weighted heavily over effective area, resulting in fairly compact arrangements of parcels around each core. Point F corresponds to a solution with total weighting on effective area, resulting in a solution of parcels in the cheaper Western Section only. Point E corresponds to a solution with consideration of both objectives, illustrating that gains in effective area come at the expense of core compactness

distance is weighted heavily over effective area, a planner is able to obtain a solution which results in a fairly compact set of parcels, solution D (Fig. 7D). As the weight on effective area is incrementally increased and the problem resolved, solutions that encompass greater effective area are obtained, but a planner gives up some of the compact nature of the solution (Fig. 7E). In addition, as effective area is weighted more heavily, more selections are made from the western section, reflecting the cheaper acquisition costs in the west. Solution F (Fig. 7F), which reflects total weighting on the effective area objective, results in a solution in which only parcels in the western section are selected. This suggests that if a planner is interested in acquiring as much effective grassland habitat area as possible, then one would be advised to follow a strategy of protecting parcels in the west.

Discussion

Protecting and restoring grassland for open space and avian conservation are important goals of land-use planners in suburban counties surrounding Chicago. We used optimization decision models to analyze tradeoffs between alternative protection goals. One goal was to minimize total pairwise distance between newly protected parcels and existing reserves, a measure of the proximity of protected parcels to the existing cores. The second goal was to acquire (and restore if necessary) as much grassland habitat as possible in a particular location for a given budget, without regard for patch size or spatial arrangement. We analyzed how the parcels selected for protection change as protected effective area is traded off against distance. As total distance was weighted more heavily, the parcels selected coalesced around core reserves but protected less area in the process. If a large, fairly compact core area with additional grassland nearby is attractive to more grassland bird species, as some grassland bird literature suggests (Helzer and Jelinski 1999, Johnson and Igl 2001, Davis 2004), then this trade-off may well be worthwhile. As area was weighted more heavily, the parcels selected were scattered and unconnected but a higher proportion of the landscape was habitat. If maximizing the area of protected habitat surrounding existing reserves is preferable, as some grassland bird literature suggests (Bakker and others 2002), then this option may be worthwhile.

We incorporated the concept of effective habitat area into our decision model to consider neighboring land conditions and edge effects in the selection and design of habitat reserves. If effective habitat area had not been utilized and we were simply interested in maximizing total acquired grassland habitat and minimizing total distance to already-protected core habitat, the model would have selected parcels up until the budget limit was met. We suggest that the actual quality of the resulting grassland reserve under this selection strategy would be overstated since the amount of habitat actually used by grassland birds would be less than what total area of the selected parcels suggests. To our knowledge, this is the first time neighboring land conditions have been explicitly utilized in a reserve site selection model, and the first model which addressed edge effects through this type of modeling construct.

The spatial patterns in the parcel selections as we changed the weights on the two reserve-design objectives were caused by differences in the price per unit area of effective habitat among the parcels. When maximization of effective habitat area was weighted more heavily, parcels that had relatively high ratios of effective habitat area to parcel area and/or parcels with relatively low or no restoration costs were selected. These were parcels classified as grasslands and/or parcels not located close to woodlands, roads, or urban areas, i.e., effective habitat area equals the total parcel area. In our data set, these parcels were scattered throughout the county. When minimization of distance to the existing core areas was more heavily weighted, parcels in the vicinity of the core areas were selected. In our data set, we found that many of these "close" parcels had relatively low ratios of effective habitat area to parcel area and high restoration costs which made them desirable choices when distance mattered but not likely to be selected when the area objective was weighted more heavily. It is important to point out that the two reserve design objectives (distance versus area) don't necessarily have to be in direct conflict with each other. However, in our model they do result in very different spatial arrangements of selected parcels because parcels located in close proximity to the existing cores have relatively high prices per hectare of effective grassland area as a consequence of high restoration costs and adverse influences from roads, urban areas, and/or woodlands.

In addition to the total area and proximity objectives that we analyzed, grassland bird biologists also recommend protecting and restoring large, contiguous areas of grassland habitat because these areas support more bird species with possibly higher nesting success (Herkert and others 1996, Helzer and Jelinski 1999, Johnson and Igl 2001, Herkert and others 2003, Davis 2004). While our model did not explicitly attempt to create contiguous areas of grassland habitat of minimum size, it is still useful to assess how well our solutions performed with respect to this additional management guideline. We assumed that areas of contiguous habitat greater than 100 ha are desirable because minimum area requirements for the occurrence of most grassland bird species are 100 ha or more (Herkert and others 1996) and reproductive success of grassland birds is lower in patches less than 100 ha (Herkert and others 2003). When only the central section of Kane County was considered, the best solution in terms of this additional management guideline was the one that minimized pairwise distance between the selected parcels and the core (Fig. 5A). Within the aggregate area covered by the selected parcels and the core, the largest contiguous grassland had 230 ha of effective habitat. As the total effective area was increasingly weighted over total pairwise distance in the model's objective function, the protected parcels were more dispersed and contiguous areas of habitat became smaller and more scattered. Still, relatively large contiguous areas of effective habitat were produced. For example, solutions B and C each included a contiguous area of effective habitat greater than 200 ha.

If two reserves of sufficient size can be established, the risk of habitat degradation or loss due to uncertain events may be reduced to an acceptable level. This concept of redundancy (Pressey and others 1993, Shaffer and Stein 2000) provides a strong rationale for a dual focus on the western and central sections. Simply minimizing pairwise distance produced only one relatively large contiguous area that includes the central core (Fig. 7D). Relaxing this condition, however, increasingly shifted habitat protection toward the western section and provided alternatives for establishing redundancy in grassland reserves (e.g., Figs. 7E and 7F). The optimal solution for grassland birds is likely to be found at the shoulder of the curve in Fig. 6. For example, the solution in Fig. 7E included not only one contiguous area of effective habitat of 170 ha in the central core, but also four contiguous areas ranging from 105–164 ha of effective habitat in the western section; three of these areas were separated only by roads and could potentially function as one large reserve.

While our model's objective of minimizing the distance of selected parcels from existing cores promotes a compact reserve design, the objective does not explicitly require patch contiguity or use contiguity as a measure of performance. A different objective could be formulated to account for habitat juxtaposition in a more rigorous way by selecting parcels to maximize the area of contiguous habitat fragments that exceed given thresholds for area and compactness. The thresholds for minimum fragment area and compactness could be based directly on occurrence data for area sensitive species. We are currently working on a reserve site selection model that maximizes the area of contiguous habitat patches that exceed a given size. The formulation requires enumerating sets of parcels that satisfy the contiguous area requirement and including them as clique constraints in the optimization model. Rebain and

McDill (2003) developed a similar model and applied it to a small hypothetical forest with 50 parcels. We are testing if the formulation works in a setting with 1000s of parcels.

There are other approaches to handling contiguity and compactness objectives in reserve design. Contiguity can be approached through the incorporation of graph theory and network constructs in the optimization model to minimize fragmentation in a reserve (Önal and Briers 2005, 2006, Cerdeira and others 2005). If the goal is to protect compact and contiguous areas of habitat, models can be formulated to maximize area of protected habitat and minimize total boundary length, a measure of compactness that also promotes contiguity of selected sites (Fischer and Church 2003, Önal and Briers 2003). Another approach utilizes core and buffer zone requirements for site selection, which promotes compactness and contiguity of selected sites (Williams and ReVelle 1996, 1998). Models that incorporate these spatial attributes of the reserve system could be formulated with and without existing core reserves to determine their impact on the design criteria. Alagador and Cerdeira (2007) developed a model that incorporates distance between selected sites and the nearest existing or newly selected site. Our study showed that models of realistic problems with proximity as a design criterion can be solved quickly. Models with other spatial design criteria may require much more solution time.

County land managers must carefully weigh various goals when making important, and expensive, land use protection decisions. Our contention is that optimization decision models, such as the one we have developed, can be useful tools to managers and planners in identifying feasible land use protection alternatives and sorting through the costs and benefits associated with alternative strategies.

Acknowledgments Funding for this study was provided by the USDA Forest Service, Northern Research Station. Skibbe was supported by a PACE award from Iowa State University and by the Department of Landscape Architecture. The authors thank Drew Ulberg (Kane County Forest Preserve District) and Tim Mescher (Kane County GIS) for facilitating this work, and Eric Gustafson (USDA Forest Service, Northern Research Station) and Rolf Koford (Iowa State University) for reviewing an earlier version of this article. We are also grateful for constructive comments from three anonymous reviewers which helped to improve the clarity of our manuscript.

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