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A GIS Approach to Prioritizing Habitat for Restoration Using Neotropical Migrant Songbird Criteria

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Abstract Restoration efforts to increase wildlife habitat quality in agricultural landscapes have limited funding and are typically done on a first come, first serve basis. In order to increase the efficiency of these restoration efforts, a prioritized ranking system is needed to obtain the greatest increase in habitat quality possible for the fewest amount of hectares restored. This project examines the use of a GIS based multi-criteria approach to prioritize lands for reforestation along the Kaskaskia River in Illinois. Loss of forested area and corresponding increase in forest fragmentation has decreased songbird habitat quality across the Midwestern United States. We prioritized areas for reforestation based on nine landscape metrics: available agricultural land, forest cover gaps, edge density, proximity to river, 200 m corridor area, total forest core area, fringe core area, distance to primary core value, and primary core area. The multi-criteria analysis revealed that high priority areas for reforestation were most likely to be close to the riparian corridor and existing large blocks of forest. Analysis of simulated reforestation (0, 0.5, 1.0, 5.0 10.0, 25.0, and 50.0% of highest priority parcels reforested) revealed different responses for multiple landscape metrics used to quantify forest fragmentation following reforestation, but indicated that the study area would get the greatest rate of return on reforestation efforts by reforesting 10.0% of the highest priority areas. This project demonstrates how GIS and a multi-criteria analysis approach can be used to increase the efficiency of restoration projects. This approach should be considered by land managers when attempting to identify the location and quantity of area for restoration within a landscape.

Keywords Reforestation · Multi-criteria analysis · Simulated restoration · Landscape ecology

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Introduction

Over the past 200 years, forest cover in the Midwestern United States has decreased by 50% due to increased agricultural use and residential/industrial development (Shifley and Sullivan 2002). Loss of forest cover has contributed to a decreased abundance of Neotropical migrant songbirds in the eastern United States (Robinson and others 1995; Valiela and Martinetto 2007). In addition to the overall loss of forest cover, remaining forested area is often fragmented, further decreasing habitat quality for these birds. For example, Ford and others (2001) reported that forest interior songbird populations in Indiana were negatively affected by fragmentation and isolation of forest habitat, while Donovan and Flather (2002) reported that fragmentation contributes to declining Neotropical migrant songbird populations.

Faaborg and others (1993) indicate that riparian forests are critical in the habitat management of Neotropical migrant songbird populations, and that these areas should be managed to increase connectivity of forested areas in agricultural landscapes. In general, wider forest tracts contain more Neotropical migrant species. Keller and others (1993) recommended corridors be at least 100 m wide to provide suitable habitat for area-sensitive species, while Kilgo and others (1998) reported buffers >500 m

were necessary to maintain forest interior bird species communities in South Carolina. Wider corridors are more likely to provide habitat for these width-dependent species and minimize the negative effects of forest edge (Keller and others 1993). Reproductive success of birds in wider buffers may also be increased by decreased predation of nests (Whitcomb and others 1981; Wilcove 1985), although the biology of local predator populations must be considered (Chalfoun and others 2002).

Not only is the amount of forest interior habitat within a landscape important, but the spatial arrangement of that habitat across the landscape is important as well. Connectivity of forested blocks links multiple populations across a landscape and increases species persistence (With and others 2006). This is particularly important when individual blocks of habitat do not provide sufficient resources for a sustainable population, which is common in fragmented landscapes across the Midwest (Robinson and others 1995). Belisle and others (2001) reported decreased movement across non-forested areas, highlighting the need for connected forest cover to increase movement between metapopulations.

Within the Midwest, over 90% of the land holdings are privately held (GSA 2009). Efforts to restore habitat for songbirds are often hampered by the lack of contiguous ownership across the landscape. While Government incentive programs, such as, the Conservation Reserve Program and the Wetland Reserve Program, do exist that facilitate the restoration of songbird habitat within the region, limited financial resources prevent the reforestation of all suitable areas. A need exists for an objective, quantitative measure that ranks the suitability of individual parcels for conservation or reforestation of Neotropical migrant songbird habitat in fragmented areas.

Multiple studies that have shown how a Geographic Information System (GIS) is useful in natural resource management by increasing management productivity and strengthening policy recommendations (Gustafson and Parker 1994; Schumaker 1996; Tinker and others 1998; Howell and others 2007; Zhalnin and others 2008; Brown and others 2009). A multi-criteria analysis (MCA) or evaluation (MCE) has been successfully used as a decision support tool for implementing spatially explicit natural resource protection and management recommendations. For example, Villa and others (2002) used MCA to combine multiple data layers into a final zoning plan for the Asinara Island National Marine Reserve in Italy. Phua and Minowa (2005) used MCA to identify new potential conservation areas in Malaysia. In Scotland, van der Horst and Gimona (2005) used a spatial multi-criteria analysis to develop maps that show areas with high biodiversity potential. Species were ranked based on the availability of habitat and national importance. The data could then be used to target areas for reforestation with high biodiversity potential. None of these studies, however, discussed the changes in landscape patterns that would occur if these high priority areas were restored. The purpose of this study was to develop a ranking methodology using a GIS approach that incorporates a fragmentation index and habitat suitability criteria for forest interior songbirds. This approach indicates which parcels would have the greatest impact on reducing fragmentation if they were restored to native vegetation. Reforestation of these high priority areas can then be simulated to quantify the effects of these efforts on specific land metrics.

Methods

Study Area

This study focused on a 70 km section of the Kaskaskia River within Clinton and Washington counties in southwestern Illinois. The Kaskaskia River is a major tributary of the Mississippi River. The river originates from an agricultural drainage in Champaign County and flows southwest entering the Mississippi River in Randolph County, Illinois. The study area consisted of a 1.6 km riparian buffer of the 100 year floodplain of the Kaskaskia River and its tributaries (Fig. 1). Total study area was 143,932 ha. It was comprised of 12,350 parcels owned by 6,169 landowners. Within the study area, the river meanders through one of the largest areas (nearly 12,000 ha) of contiguous bottomland forest in Illinois. Dominant species within the bottomland forest are box elder (*Acer negundo)*, silver maple (*Acer sacharrinum*), river birch (*Betula nigra*), hackberry (*Celtis occidentalis*), green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis*), and cottonwood (*Populus deltoides*). Because of the large amount of forest cover, this area contains some of the highest populations of rare and declining avian species characteristic of floodplain forest in Illinois, including Red-shouldered hawk (*Buteo lineatus*), Red-headed woodpecker (*Melanerpes erythrocephalus*), Cerulean Warbler (*Dendroica caerulea*), American Redstart (*Setophaga ruticilla*), and Prothonotary Warbler (*Prothonotaria citrea*) (Robinson 1997). Although the study area contains a large amount of forest habitat, the majority of the remaining land (approximately 120,000 ha) is used for agricultural purposes making this an ideal setting to examine forest structure in response to restoration efforts.

Data Layers

Individual Parcels

Individual parcels (contiguous blocks of ownership) were identified through a landowner registry provided by the

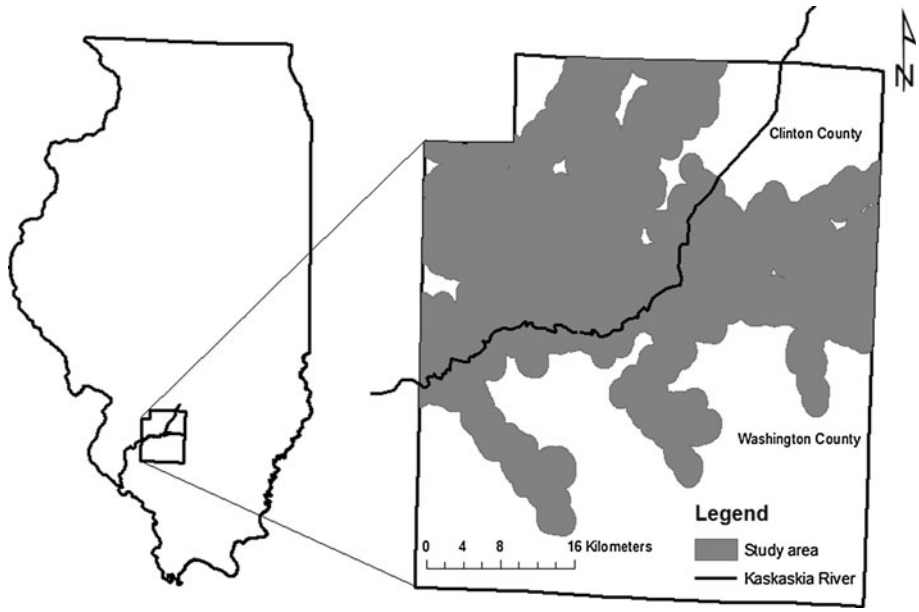

Fig. 1 The study area was located within Clinton and Washington counties in southwestern Illinois along a stretch of the Kaskaskia River between the Carlisle Lake Dam and Fayetteville, Illinois

Southwestern Illinois Resource Conservation and Development, Inc. (SWI RC&D) and given a unique identification number. Some landowners owned multiple parcels. Land parcels were included in the final analysis if parcel centers were within the study-defined 1.6 km floodplain buffer.

Land Cover

The land use/land cover map described the current status of all the lands in the study area. National land cover data were used to identify all the land cover classes within the study area (USDA 1999). Land cover data were reclassified into three categories: forest, restorable land, and un-restorable land. Land cover types that were consistent with the natural wetland, riparian, and surrounding upland ecosystems were all classified together as "forest". These areas included bottomland forest and the surrounding upland forest communities. Land cover types that differed from the forest classification were placed in two different categories. First, land cover types that were identified as developed or bare areas such as residential, transportation, industrial, commercial, quarries, or strip mines were considered unable to contribute to the natural community and unsuitable for reforestation efforts. These areas were defined as "un-restorable land" and were not considered in the habitat prioritization process. Though this land cover category was not regarded as a potential candidate for restoration, these areas played a role in the calculation of habitat metrics such as edge density and core area values. The second land cover type that differed from the forest classification was called the "restorable land" or available land category. These lands were identified as having the potential to be converted to forest cover and included planted or cultivated land, orchards, vineyards, pastures, grasslands, and old fields.

Riparian Buffer

A 100 m buffer of creeks and rivers within the study area was selected as important for high priority restoration and protection efforts. A 100 m minimum buffer (200 m corridor) width was found to be beneficial for many Neotropical migrant songbird species dependent on forest interior and riparian habitat (Keller and others 1993, Hagar 1999).

Habitat Prioritization

Habitat prioritization criteria were developed using GIS and FRAGSTATS Spatial Pattern Analysis Program (McGarigal and others 2002) to produce the nine landscape metrics (Table 1). Landscape metrics were based on objectives from the SWI RC&D to improve forest interior bird habitat (SWI RC&D 2002). In particular, specific metrics, such as distance to river and available agricultural land surrounded by forest, were chosen to assess forest interior habitat near riparian areas. These areas are critical for the success of Neotropical migrant songbirds (Faaborg and others 1993). After calculating the landscape metrics, a multi-criteria analysis was used in ArcView 3.2 to standardize and weight all nine output metrics (Table 1). Prioritization suitability followed the weighted linear combination procedure for each land parcel

$$P = \sum_{i=1}^{I} WiXi$$

Table 1 Nine metrics were used in the Multi-Criteria Evaluator process

Landscape metric	Definition	Weighted value (%)
Available agriculture hectares	Sum of all land that could potentially be reforested including orchards, vineyards, cultivated fields, and grasslands.	18.75
Distance to river	Distance of each land parcel, based on a fixed central point of each land parcel, to the Kaskaskia River. Land closer to the river was ranked with greater priority within this category.	18.75
Doughnut holes	Available agriculture parcels that are completely surrounded by forest.	15.63
Core area	Area within forest patch type at least 200 m from patch edge.	15.63
Edge density	Ratio of edge segment length of forest patches to area of forest patches	9.38
Riparian corridor	A 100 m buffer of all rivers, streams, and creeks in the study area used to identify a 200 m corridor. Riparian sites were given higher priority for conversion to forest cover.	9.38
Primary core area	Forest interior (core) areas that are directly connected to or associated with the Kaskaskia River.	6.25
Fringe core area	Forest interior (core) areas that are disconnected from the primary Kaskaskia River core area, by means of forest fragmentation.	3.13
Distance to primary core	Distance of each land parcel to core area, based on a fixed central point of each land parcel. A land parcel closer to a core area was ranked with greater priority within this category.	3.13

All values were standardized and weighted according to habitat significance

where W is the assigned weight and X is the standardized score of each habitat criterion ($_i$). Each parcel's score (P) was then ranked in a descending list from highest to lowest reforestation priority.

Simulated Reforestation

The prioritized landowner parcel layer generated in the habitat prioritization analysis was used to compare the effects of simulated reforestation efforts on mitigating forest fragmentation. Seven simulations using 0.0% (current condition), 0.5%, 1.0%, 5.0%, 10.0%, 25.0%, and 50.0% of the highest priority parcels for reforestation were used in the analysis. All restorable lands in each landowner parcel within the six restored parameters ($\geq$0.5%) were reclassified as 'forest' representing a mock reforestation effort. After reclassification, four landscape metrics (edge density, total core area, number of disjunct core areas, and connectance index) were then calculated using FRAGSTATS (McGarigal and others 2002). Edge density (m/ha) was equal to the sum of the forest patch perimeters (m) divided by total landscape area (ha). Landscapes that have a higher edge density value have a corresponding negative relationship to forest interior habitat. Total core area (ha) equals the sum of the interior forest area in the landscape. Core areas were at least 200 m from the forest edge to account for forest interior bird habitat criteria. Number of disjunct core areas was equal to the sum of all separate total core areas contained within a landscape. Within a single forested patch there may be several disjunct core areas. Connectance index (%) was equal to the number of joinings between patches divided by the total number of joinings possible. The greater the number, the more connected a landscape is. When calculating a connectivity index, a 100 m threshold was used as a maximum limit of forest cover to the nearest forest cover.

Landscape metrics were chosen to identify edge and interior habitat (edge density and total core area metrics), as well as connectivity across the landscape (number of disjunct core areas and connectance index). Following calculation in FRAGSTATS, individual metrics were graphed to compare trends of the metric with baseline condition (no reforestation) and increased reforestation effort. In addition, a comparison was made between the increases in restored area and corresponding increase in total core area.

Results

Parcel Prioritization

Visual results of the prioritization are presented in Fig. 2. The final aggregate GIS map layer provides a color-scale corresponding to reforestation potential ranking. The pattern that emerges from initial review of the output image is a ranking that favors reforestation of larger tracts with closer proximity to the river.

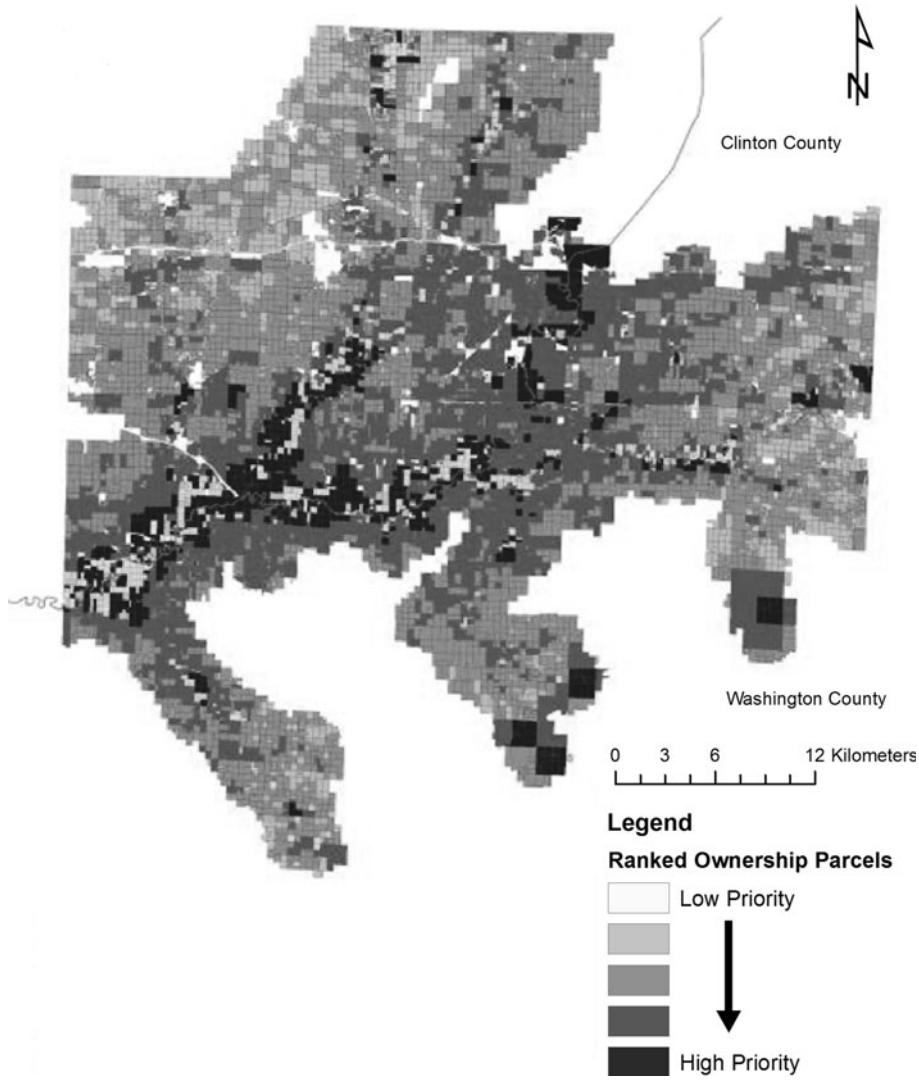

Fig. 2 Landowner parcels ranked according to habitat restoration priority for forest interior birds

Simulated Reforestation

Prioritized areas were grouped into seven categories: reforestation of 0.0% (current condition), 0.5%, 1.0%, 5.0%, 10.0%, 25.0%, and 50.0%, of the highest priority areas which corresponded to restoring between 62 and 6,175 parcels and a total reforested area of 609–76,439 ha (Table 2). Individual metrics differed greatly in their response to increased reforestation effort. Before reforestation, edge density was 16 m/ha. The metric decreased sharply from 0 to 5% reforestation, but appeared to level off with reforestation effort greater than 10% (Fig. 3a). Total core area prior to reforestation was 4,094 ha and increases in total core area showed a positive linear relationship with increased reforestation (Fig. 3b). Reforesting 50.0% of the eligible hectares resulted in over a ten-fold increase in total core area. The number of disjunct core area decreased 20% from the current condition to 5.0% reforestation, but then nearly doubled from that point compared to the number at the 50.0% reforestation point (Fig. 3c). The connectance index was low prior to reforestation (2.5%) and remained low until the 25% reforestation level where it nearly doubled to 4.5%. The index continued to increase exponentially to the 50.0% reforestation point (Fig. 3d).

Table 2 Parcels restored (%) and corresponding number of parcels and restored area after simulated reforestation efforts

Parcels Reforested (%)	Number of parcels	Restored area (ha)
0	0	0
0.5	62	609
1.0	123	922
5.0	617	3562
10.0	1235	9508
25.0	3087	36732
50.0	6175	76439

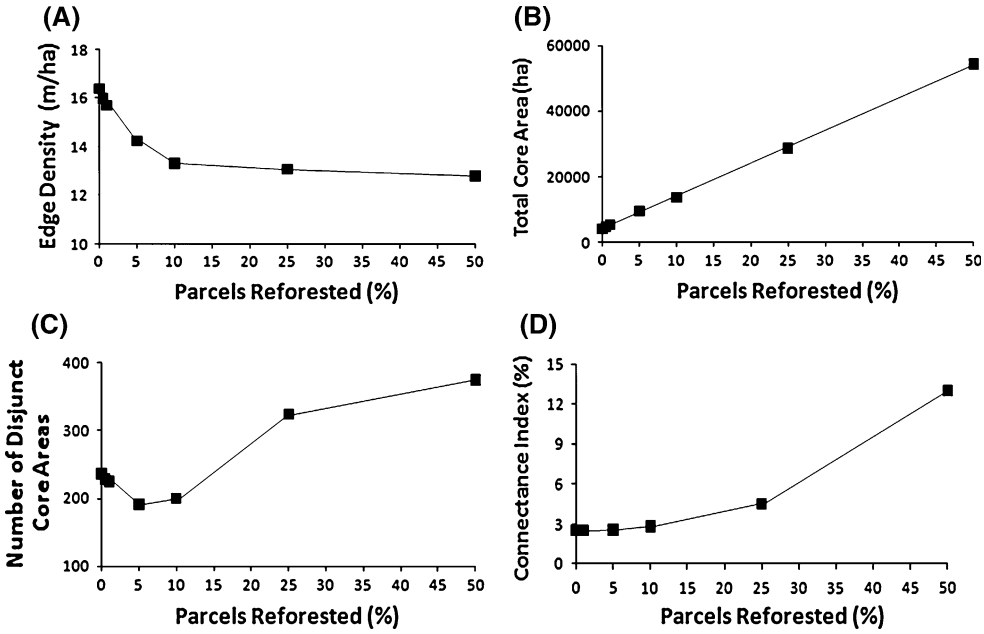

Fig. 3 Effects of simulated reforestation on four landscape metrics, **a** edge density, **b** total core area, **c** number of disjunct core areas, and **d** connectance index (%), in the study area

Comparison between the amount of restored area and increase in total core area showed a varied response among the reforestation efforts. Increasing restored area resulted in a positive tradeoff of total core area up to the 5.0% reforestation level (Fig. 4). At the 5.0% level, one hectare restored resulted in 1.5 ha of total core area gained. At the 10.0% reforestation level, there was a 1:1 tradeoff in area restored and total core area gained. Greater reforestation showed a decreased tradeoff. For every ha restored at the 25.0% and 50.0% reforestation level, 0.6 ha of total core area was gained.

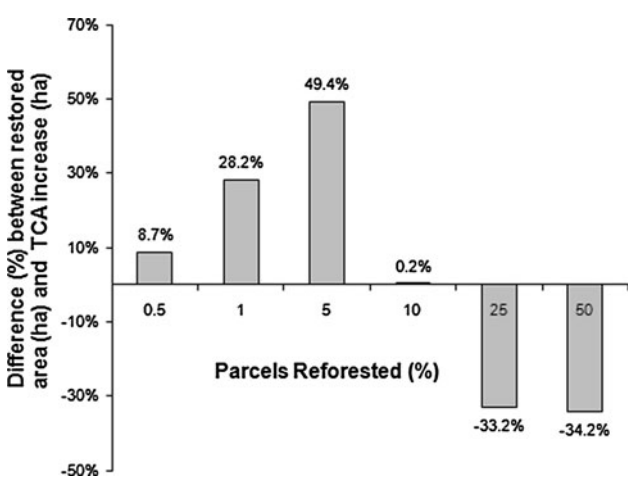

Fig. 4 Difference (%) between restored area and the corresponding increase in total core area (TCA) for different parcels restored based on highest priority in a simulated reforestation effort

Discussion

GIS Application

This project demonstrates how using a GIS with a multi-criteria analysis can be useful to identify and rank key private land holdings to efficiently reduce forest fragmentation across a landscape. Our analysis identifies thresholds in individual landscape metrics so that land managers know not only where the highest priority areas are, but how much land would need to be restored to significantly change the landscape pattern. The patterns seen among the observations of the parcel rankings in this study indicate that, as expected, there is a relationship between distances from the river, core forested area, and parcel size. The output map describes where conservation practices should be targeted on the landscape on a parcel level, for which a purely biologic model could not be as easily interpreted or applied at the landowner level. This project demonstrates the need to look at land conservation in a spatial arrangement that accurately accounts for the private land boundary. Findings suggest that due to the ranking criteria, sites ranked highest for reforestation were consistent among their ability to increase large blocks of forest and increase connectivity for forest interior birds in the lower Kaskaskia River and its tributaries.

Simulated Reforestation

Three landscape metrics evaluated after simulated reforestation (edge density, number of disjunct cores areas, and connectance index) showed a non- linear response to

increased reforestation. These results support the findings of Gustafson and Crow (1996) which showed a nonlinear response for multiple landscape metrics following a simulated harvest of the Hoosier National Forest using the program HARVEST. We identified a threshold of approximately 25.0% reforestation before connectivity increased in the landscape. Edge density, however, had a threshold of 10.0% reforestation and did not decrease significantly past that level. Perhaps the most complicated metric response to increased reforestation was number of disjunct core areas. This number decreased as the number of parcels restored reached 5% but then increased as small outlying forested parcels were built upon and riparian corridors narrower than 400 m were widened creating new core areas, which is a typical pattern found in the Midwest (Chalfoun and others 2002). As this progression of forest building continues, the number of disjunct core areas will eventually peak, and then decrease to zero once the entire study area becomes forested.

As we reforest land using the simulation model, the trend is toward less forest fragmentation on the landscape. Total core area and the connectance index increase, while the amount of edge decreases with every land parcel restored, albeit at different rates. As land is restored, however, there is a tradeoff in the amount of total core area gained (Fig. 4). For example, when the top 1% of land parcels is reforested, the amount of land being restored is 922 ha, and the total core area gained by reforesting those parcels is 1,182 ha. However, reforesting the top 25% of the land parcels is equivalent to reforesting 36,732 ha, but only 24,549 ha of total core area is gained. This is expected because as more area is reforested, only lower priority land is left for reforestation according to the prioritization analysis and, thus you gain fewer benefits from reforestation.

Neotropical Migrant Songbird Habitat

Building and restoring large contiguous blocks of forest land in the Lower Kaskaskia River corridor is essential for improving habitat for forest interior Neotropical migrant songbirds and other related wildlife. However, land managers should proceed with caution to ensure that restoration efforts do not create a population sink for forest birds (Lloyd and others 2005). In bottomland areas, Twedt and others (2010) recommend increasing tree density and height within mostly forested landscapes of >8,000 ha to effectively restore areas for stable populations of forest birds. Rittenhouse and others (2010) recommend the use of habitat suitability index models to predict avian success following changes in habitat management. If it is determined that restoration efforts create an ecological trap for forest birds in a restored Kaskaskia River watershed it might be more appropriate to pursue landscape restoration elsewhere.

Management Implications

Criteria used in the GIS approach to prioritize landholding in this study are not limited to improving songbird habitat and could be modified to fit the goals and objectives for a given management plan. Once adjusted, GIS, and subsequent analysis of simulated restoration, could be used to identify priority areas in any landscape. Identifying land parcels with the highest priority for restoration will increase the productivity of natural resource managers, making it easier for them to plan project budgets, apply for grant funding, and strategically organize reforestation activities. In addition, it is impractical to pay for restoration of an entire landscape, and efforts should be made to conduct restoration in targeted areas so that funding agencies maximize environmental benefit at the lowest economic cost (Secchi and others 2008). For example, in the Midwest, reforestation of an entire landscape is unlikely because of the high demand for agricultural products. However, if forest fragmentation can be significantly reduced by strategically reforesting 10–25% of all possible areas, then natural resource managers will have a targeted, and perhaps more achievable, goal for habitat enhancement. Having realistic, specific goals for a proposed conservation area will most likely encourage landowners to participate in large scale reforestation efforts if they can see how their property will impact a broader conservation area. A more thorough understanding of landowner needs, wants, and objectives in priority reforestation areas may aid in landowner cooperation and project success. A survey of these key landowners may yield additional data upon which natural resource managers can base management decisions.

Conclusion

Forest fragmentation has been shown to negatively impact populations of certain area-sensitive Neotropical migrant songbird species throughout the Midwest. The conversion of forested land to other land uses, such as agriculture, in the Kaskaskia River watershed of southwestern Illinois has decreased the amount of interior forest habitat available for nesting success of these birds. This project describes a GIS approach to assist landowners and agencies in assessing the amount of forestland in the region and prioritizes those non-forested lands available for reforestation according to their importance for bird habitat and reduction of forest fragmentation. Overall, this project demonstrates the use of a ranking system that is unique to landowner parcel data. Many landscape habitat models have succeeded in quantifying habitat suitability within the bounds of natural features, but they often ignore the important reality of landowner boundaries. Achieving conservation on the

ground is accomplished most effectively when we understand not only landscape and natural features with their corresponding natural boundaries, but also understand, respect, and work within the property boundaries of individual landowners.

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