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An Ecoregional Context for Forest Management on National Wildlife Refuges of the Upper Midwest, USA

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Abstract

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forest patches are generally larger and more aggregated than in associated ecoregions. Broadleaf taxa have increased in dominance in the ecoregions and displaced fire-dependent taxa such as pine (Pinus spp.) and other coniferous species; these changes in forest composition have likely also affected refuge forests. Despite compositional changes, larger forest patches on refuges suggests that they may provide better habitat for area-sensitive forest landbirds of mature, compositionally diverse forests than surrounding lands if management continues to promote increased patch size. We reason that although finescale research and monitoring for species of conservation priority is important, broad scale (ecoregional) assessments provide crucial context for effective forest and wildlife management in protected areas.

Keywords

conservation, ecoregions, forest restoration, land cover, landscape metrics, National Wildlife Refuse System

Disciplines

Environmental Policy | Environmental Studies | Forest Management | Natural Resources Management and Policy

Comments

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Keywords Conservation · Ecoregions · Forest restoration · Land cover · Landscape metrics · National Wildlife Refuge System

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Introduction

Ecosystems may be defined as geographic units of a landscape that include all inter-related natural phenomena that can be delineated by boundaries (Rowe 1961; Bailey 2009). Defining a specific ecosystem has been the source of much debate (Blew 1996), but pragmatic use of the concept by land management agencies has often followed a geographical approach (Bailey 2002, 2009). Ecosystems are understood in a hierarchy, whereby ecosystems at higher levels of the hierarchy impose processes that drive ecological structure and function at lower levels (Turner and others 2001; Bailey 2009). This geographical approach emphasizes land and the broader abiotic drivers of biodiversity, rather than species or habitat *per se* (Albert 1993; Barnes 1993; Bailey 2009). Defining ecosystems at regional scales (ecoregions) is of increasing interest to land management agencies because they contain large functional landscapes that provide context for smaller parcels of land (Cleland and others 1997; Bailey 2002, 2009). Biodiversity conservation in this context depends heavily on land management at multiple spatial and temporal scales and the participation of multiple stakeholders (Askins 2000; Wiens 2009). An example of such an ecoregional conservation framework in practice is the national hierarchical framework of ecological units developed by Cleland and others (1997).

The U.S. Fish and Wildlife Service (USFWS) manages nearly 60 million hectares (ha) as the National Wildlife Refuge System (NWRS), with a mission to conserve, preserve, and restore lands for the wildlife that they support (Schroeder and others 2004; Meretsky and others 2006). Overall management guidance for the NWRS is provided by the 1997 Refuge Improvement Act (Public Law 105-57-October 9, 1997), which stipulates that managers should focus on restoration and enhancement of fish, wildlife, and plant populations. NWRS land managers have been encouraged to favor ecologically-based wildlife habitat management, with restoration to historic conditions where and when possible (Schroeder and others 2004; Meretsky and others 2006). Consequently, some NWRS planners and land managers have broadened their focus from highly specific wildlife habitat variables for a single species or taxon to more general ecosystem patterns important to multi-species and ecosystem conservation (Corace and others 2009; 2010a, b). Such a policy shift provides the opportunity not only for the conservation and management of wildlife species, but also for the management and restoration of whole ecosystems.

The protected area approach of the NWRS uses a legislative mandate to exclude large areas from further development and potential degradation. Using refuges to protect habitat for one or a few species has become the standard for biodiversity conservation across both the United States and the world (Noss 1996; Bruner and others 2001; Chape and others 2005). However, many protected areas are becoming increasingly isolated from the ecological function of their surroundings due to anthropogenic activities that alter the larger ecoregion (Hansen and others 2004; DeFries and others 2005; Schulte and others 2007; Radeloff and others 2010; Gimmi and others 2011). In contrast to the protected area itself, ecoregional changes typically include extensive land development and ownership that fragments the landscape (Theobald and others 1997; Swenson and Franklin 2000) or anthropogenic changes in vegetation composition that may negatively affect biodiversity (Rochelle and others 1999; Schulte and others 2007). In the Upper Midwest, ownership patterns are relatively fine-scaled and highly diverse (Radeloff and others 2005). These patterns require conservation planning and cooperation with landowners beyond the boundaries of any protected area or refuge (Probst and Crow 1991; DeFries and others 2007; Gimmi and others 2011). In response to this need, the USFWS has created Landscape Conservation Cooperatives to address conservation needs that span greater space than any single ownership (Department of Interior Secretarial Order No. 3289, 2010).

Broad-scale ecological assessments of refuges and their associated ecoregions are critical components of cooperative conservation or restoration efforts in many parts of the Upper Midwest. Forests on refuges that are representative of the greater ecoregion provide important opportunities for ecological restoration because of the reduced emphasis on commodity production or motorized recreation within the NWRS (Meretsky and others 2006). Scott and others (2004) provided an ecological assessment of NWRS lands in the conterminous United States, but did not account for the regional context of the refuges. Consequently, the importance of an individual refuge to the conservation of the corresponding ecoregion could not be determined.

We conducted an assessment of landscape patterns within four relatively large NWRS refuges and their individual ecoregions to facilitate forest planning and management and provide a forest conservation and restoration baseline for refuges in the Upper Midwest. Specifically, we synthesized published data and other data sets to: (1) compare existing spatial patterns for forests and other land cover types between refuges and their associated ecoregions; (2) examine changes in forest composition within the four ecoregions to assess the opportunities for ecological restoration on the refuges; and (3) explore the implications of this assessment for wildlife conservation—specifically USFWS Midwest Region Conservation Priority forest landbird species (USFWS 2002). We hypothesized that: (1) land cover in the four refuges is representative of their associated ecoregions, although rarer cover types in the ecoregion would be over-represented in refuges; (2) forest composition changes at an ecoregional scale are substantial; and (3) landscape patterns within refuges would facilitate the conservation of a subset of the landbird species found within the wider ecoregions.

Methods

Study Area

The study area consisted of four refuges that together represent the majority of forested land under NWRS ownership in the Upper Midwest region. Although many refuges in the region are largely non-forest (Scott and others 2004), the methods we use here are of special interest in other regions of the NWRS (e.g., the northeastern and southeastern US) where forested refuges are more common. Each of the four refuges we studied is located in a different ecoregion of the Laurentian Mixed Forest Province of Michigan, Wisconsin, and Minnesota (Cleland and others 1997; Fig. 1). The refuges include: Seney National Wildlife Refuge (38,541 ha) on the Seney Lake Plain in the Upper Peninsula of Michigan; Rice Lake National Wildlife Refuge (7,406 ha) on the St. Louis Moraines in east-central Minnesota, Tamarac National Wildlife Refuge (17,295 ha) on the Pine Moraines and Outwash Plains of northwestern Minnesota; and Kirtland's Warbler Wildlife Management Area (WMA) on the Kirtland's Warbler High Sand Plains of the northern Lower Peninsula of Michigan. Kirtland's Warbler WMA differs from the three other refuges in that it was created in 1980 under the authority of the Endangered Species Act for the conservation of an endangered species (Kirtland's warbler, *Dendroica kirtlandii* Baird) and contains 125 separate tracts totaling 2,705 ha (USFWS 2009b). The four ecoregions together include >3 million ha; the four refuges include about 62,000 ha.

The 40 tree species used in our analyses included 31 broadleaf and 9 coniferous species (Schulte and others 2007; Appendix 1) whose distribution varied across the study area. Species such as oak (*Quercus* spp.) have conservation value for their production of wildlife forage. Other tree species are critical for endangered species because of their importance as breeding habitat (e.g., jack pine, *Pinus banskiana* Lamb., and Kirtland's warbler) or migratory bird species of high conservation priority (e.g., aspen, *Populus* spp., and golden-winged warbler, *Vermivora chrysoptera* L. or American woodcock, *Scolopax minor* Gmelin). Notably, some tree species are of conservation concern because of alterations in their distribution, abundance, and/or associated ecological processes, such as various pine species (*Pinus* spp.) that characterize communities found in fire-dependent ecosystems (Drobyshev and others 2008a).

Data Collection and Analyses

We first analyzed land ownership data within the four ecoregions using a geographic information system (GIS). Our objective was to place forest conservation and restoration possibilities for the refuges in context with land ownership in the surrounding ecoregion. For the two Michigan ecoregions, we used the Conservation and Recreation Lands (CARL) dataset (Ducks Unlimited 2007) that classified ownership into six categories: Federal, State, County, local, Non-governmental Organization (NGO), and private. Areas not coded in one of the above categories were categorized as 'no data' during analysis. For the two ecoregions in Minnesota, GAP Stewardship data (MN DNR 2008) were used and were classified into nine categories: Federal, State, County, other public, private, private conservancy, private industrial, private non-industrial, and tribal. We then used Forest Inventory and Analysis (FIA) data (Miles and others 2001) to classify ownership of only forested land in the four ecoregions into five categories of land ownership, including National Forest (USDA Forest Service), Other Federal (primarily National Wildlife Refuges), State, Local Government (County, Municipal, etc.) and Undifferentiated Private (Miles and others 2001).

We next quantified landscape patterns for all land cover types that represented >10% of the area at both the refuge and ecoregion scale using 2001 National Land Cover Data (NLCD, 30 m minimum mapping unit) (see Appendix 2). FRAGSTATS (McGarigal and others 2002) was used to calculate metrics of landscape composition (patch richness, patch density) and indices of fragmentation (largest patch index, landscape shape index, mean patch area) revealed in the NLCD dataset (see Table 1 for description of metrics). Landscape metrics help land managers make informed decisions regarding the management of landscape patterns (Forman and Godron 1986), and have been used to assess wildlife habitat for area-sensitive species (Robbins and others 1989; Boulinier and others 1998), including neotropical migrant birds (Fauth and others 2000). All refuges were 2–5 times the size of the largest patch in each landscape, such that the non-natural political boundaries of the refuges were unlikely to greatly bias landscape metric calculation (O'Neill and others 1996).

To examine changes in forest composition in the four ecoregions and their associated refuges, data from the original General Land Office Surveys (1836–1907) were transcribed into a GIS database and used to describe pre-Euro-American conditions (Stewart 1935, Schulte and Mladenoff 2001). This analysis was conducted at the ecoregion scale (Schulte and others 2007), then compared to near-current conditions (early to mid-1990s) characterized by FIA data at ecoregion and refuge scales (Miles and others 2001). Forest composition change was described as the change in relative dominance (by basal area, m^2 ha^{-1}) of tree taxa (see Schulte and others 2007). Notably, some tree taxa were grouped at generic rather than species level (e.g., all pine species are grouped as *Pinus*) when data lacked specificity. Furthermore, historical data were not grouped into present-day land ownership classification; analysis of compositional change was therefore confined to each ecoregion and could not be refuge-specific.

As an example of how landscape patterns may be integrated into a top-down framework for wildlife habitat

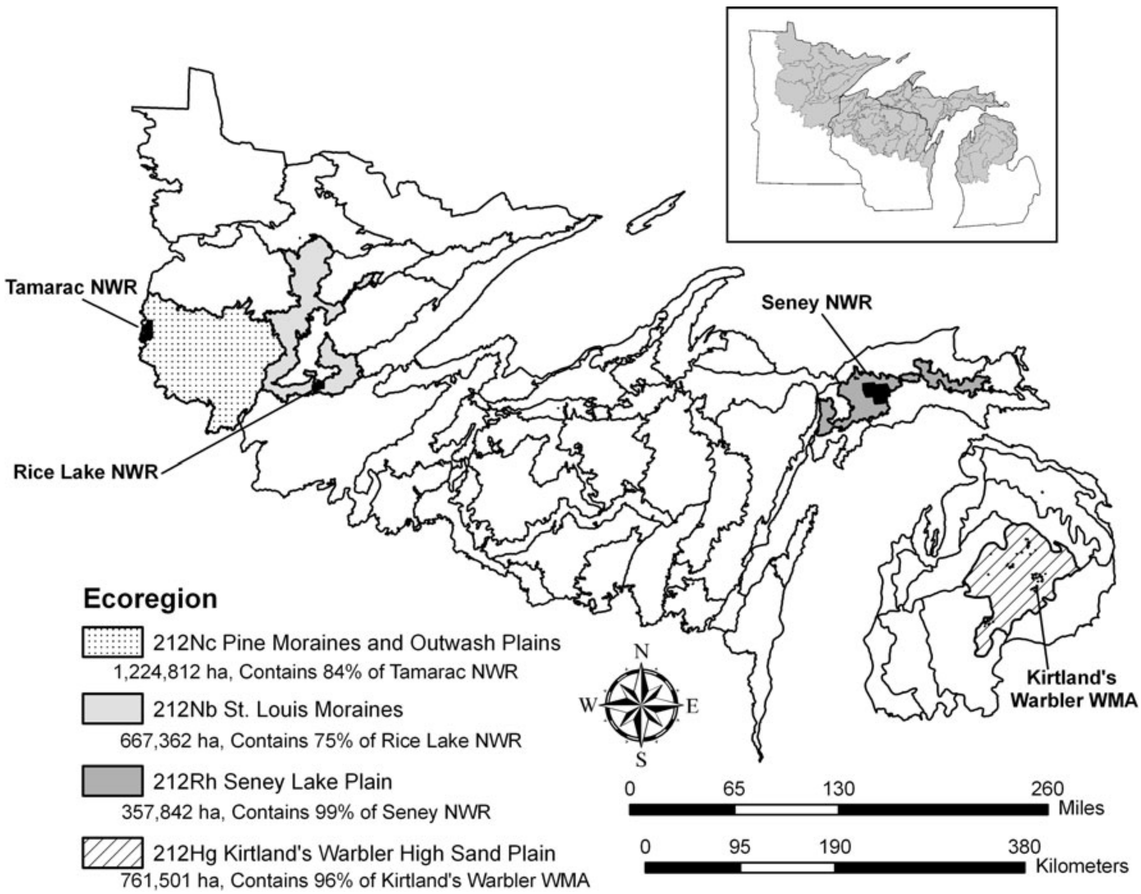

Fig. 1 Four refuges comprising study in Michigan, Minnesota and Wisconsin and their associated Laurentian Mixed Forest Province ecoregions as defined by Cleland and others (1997). Irregular lines demarcate other ecoregions that are not part of this study. The location of the Province within Michigan, Minnesota, and Wisconsin is shown via shading in the inset map

Table 1 Landscape metrics used to describe landscape patterns for four refuges and their associated ecoregions in the Upper Midwest

Metric	Description	Units	Index
Patch density	Number of patches per unit area	#/100 ha	Landscape composition
Patch richness	Number of patch types on a landscape	–	Landscape composition
Landscape shape index	Total length of edge divided by the minimal length of class edge possible for a maximally aggregated class	%	Landscape fragmentation
Mean patch area	Mean patch size of all patches on a landscape	ha	Landscape fragmentation
Largest patch index	Percentage of the landscape comprised of the largest patch	%	Landscape fragmentation

planning and management, we first used the USFWS Midwest Region Conservation Priority list of species (2002) to identify breeding forest landbird species at each of the four refuges. Forested habitat types and the relative abundance during the breeding season used by each species were identified for each refuge based upon published research (Crozier and Niemi 2003, Corace and others 2010a), planning documents (USFWS 2009a, b), and professional experiences. General forest habitat types used by each species were characterized by adapting NLCD coding and making note of specific important structural attributes (e.g., snags, mature trees). We then drew inferences about the opportunity for forest management to benefit these species at each refuge based on the spatial patterns of forest composition described above, the relationship of these compositional spatial patterns to ecological processes, and landscape metrics and area sensitivity (Robbins and others 1989; Boulinier and others 1998).

Results

Land Ownership Patterns

Major differences were found in the proportion of each ecoregion in public versus private land. Seney NWR was the largest of the four refuges and was located in the ecoregion with the most public land (Seney Lake Plain—80%). Tamarac NWR was the second-largest refuge and was located in the ecoregion with the smallest proportion of public land (Pine Moraine and Outwash Plain—31%). Kirtland's Warbler High Sand Plains had 57% of its area in public lands, and St. Louis Moraines had 46%. State and federal-owned land represented >98% of public land in all ecoregions, although the proportion of state to federal land varied among the ecoregions. Most ecoregions included public land dominated by state ownership, with 68, 77, and 81% public land owned by states in the Kirtland's Warbler High Sand Plains, St. Louis Moraines, and Pine Moraine and Outwash Plain, respectively. Only the Seney Lake Plain ecoregion was dominated by federally owned public land at 53%.

Land Cover Patterns

Forested types—deciduous forest, evergreen forest, or woody wetlands—were the dominant land cover in all ecoregions and their associated refuges (Fig. 2). Seney Lake Plain had the highest proportion of forest area among the four ecoregions at 67%, and Pine Moraine and Outwash Plain the least at 44%. Proportion of forest on refuges ranged from 55% at Tamarac NWR to 38% at Kirtland's Warbler WMA, although some forested land in young jack pine plantations used for Kirtland's warbler management was likely misclassified as "herbaceous". Refuges varied in how well they represent their greater ecoregion in terms of land cover. Three of the refuges contained a higher proportion of cover types (e.g., wetland communities) particularly beneficial to some wildlife species (such as waterfowl or marshbirds) than their associated ecoregion. Rice Lake NWR contained a higher proportion of open water compared to the St. Louis Moraines ecoregion; Seney NWR was dominated by woody and emergent wetlands while evergreen forest is a more dominant type on the Seney Lake Plain; and Tamarac NWR contained a higher proportion of emergent wetlands than was found in the Pine Moraine and Outwash Plain ecoregion (Fig. 2). Kirtland's Warbler WMA was the sole exception to this pattern, as it overemphasized terrestrial cover types compared to the greater ecoregion in response to the habitat requirements of the Kirtland's warbler. Notably, a considerable portion of both St. Louis Moraines (36%) and Pine Moraine and Outwash Plain (45%) was devoted to land cover types that singly comprised <10% of the area of these ecoregions.

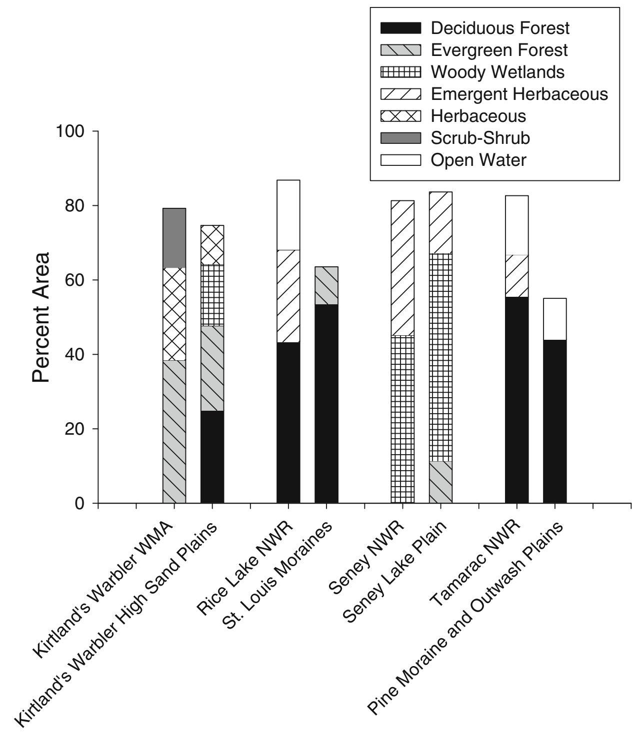

Fig. 2 Percentage of each refuge and its associated ecoregion in National Land Cover Data (2001) land cover types; only land cover types comprising ≥10% of the area were examined

Landscape pattern was similar between refuge and ecoregion in many ways, but differed in patch size and aggregation. Patch density was similar between refuges and their associated ecoregions, ranging from 11 to 16 patches/100 ha in three of the ecoregions and three of the associated refuges (Table 2). Kirtland's Warbler WMA (30.6) was an outlier that exemplifies the non-contiguous nature of this refuge. Patch richness varied little between refuge and associated ecoregions, or among refuges or ecoregions. Rice Lake NWR was most different from its ecoregion, having 12 patch types compared to 15 in the St. Louis Moraines. Landscape shape index (LSI; a measure of patch aggregation that indicates less aggregated patches as it increases) ranged 2–15 times greater in ecoregions than for the refuges within them (Table 2), suggesting a less fragmented landscape within the refuges compared to their associated ecoregions. Seney NWR showed the largest LSI, and was most similar to its ecoregion in terms of this metric. This finding supports the work of others that have noted the heterogeneous nature of this landscape (Crozier and Niemi 2003). Mean patch area was also similar between refuges and ecoregions, with larger patch size found in Tamarac NWR and Rice Lake NWR compared to Pine Moraine and Outwash and St. Louis Moraines, respectively; smaller patch size in Kirtland's Warbler WMA compared to the Kirtland's Warbler High Sand Plains; and about equal patch size in Seney NWR compared to the Seney Lake Plain. Notably, patch size across

Table 2 Landscape metrics based on National Land Cover Data (2001) by refuge and associated ecoregion for four refuges in the Upper Midwest

Refuge and ecoregion	Area (ha)	Indices of landscape composition		Indices of landscape fragmentation		
		Patch density (#/100 ha)	Patch richness	Landscape Shape Index	Mean Patch Area (ha)	Largest Patch Index (%)
Seney NWR	38,541	12.62	14	100.69	7.92	21.85
Seney Lake Plain	357,842	12.43	15	231.25	8.05	6.40
Tamarac NWR	17,295	13.47	14	40.79	7.42	47.85
Pine Moraine and Outwash Plains	1,224,811	16.13	15	372.70	6.20	13.48
Rice Lake NWR	7406	11.23	12	22.40	8.90	21.58
St. Louis Moraines	667,362	16.31	15	286.99	6.13	13.13
Kirtland's Warbler WMA	2705	30.56	13	23.03	3.27	4.19
Kirtland's Warbler High Sand Plains	761,501	18.52	15	340.88	5.40	1.07

See Table 1 for a definition of landscape metrics

the ecoregion was higher than in the corresponding refuge for those ecoregions having the least amount of public land and the most diverse land ownership patterns (Pine Moraine and Outwash Plain and St. Louis Moraines). All refuges had a larger largest patch index than their associated ecoregion, indicating the preservation of large, unbroken tracts of land within the refuges compared to the ecoregions (Table 2).

Landscape patterns of forest types on each refuge highlighted the major differences in patterns of forested land cover among the refuges. Woody wetlands were an important component of Seney NWR and occurred as the largest (mean patch area = 14.5 ha; largest patch index = 21.9%), most common (3.1 patches/100 ha), and least aggregated (shape index = 130.1) patch type on the refuge (Table 3). In contrast, Tamarac NWR and Rice Lake NWR were characterized by large patches of terrestrial (deciduous) forests that were well aggregated, and Kirtland's warbler WMA was characterized by small, numerous patches of evergreen forest that again reflect the non-contiguous nature of this refuge (Table 3). Landscape metrics for Seney NWR and Kirtland's Warbler WMA suggested a highly heterogeneous arrangement of forest patches across the landscape, with considerable diversity in forest types and patch shapes. Conversely, Tamarac and Rice Lake NWRs were characterized by much greater average patch areas in primarily deciduous forests, with relatively less heterogeneity in terms of shape (Table 3).

Changes in Forest Composition

All ecoregions experienced considerable change in forest composition over the past century, and the occurrence of many tree taxa was altered to an even greater degree than suggested previously by Schulte and others (2007) for the Upper Midwest. For deciduous species, ashes (*Fraxinus* spp.) and aspens (*Populus* spp.) increased in dominance to a greater degree than suggested by Schulte and others (2007) in two of the four refuges; American basswood (*Tilia americana* L.) increased in three of the refuges; elms (*Ulmus* spp.) decreased in dominance in three of the refuges and increased in the fourth; maples (*Acer* spp.) increased in two of the refuges and oaks (*Quercus* spp.) in one; and American beech (*Fagus grandifolia* Ehrh.) decreased in one (Fig. 3). Conversely for coniferous species, decline of eastern hemlock (*Tsuga canadensis* (L.) Carrière) was greater in three of the ecoregions compared to the overall Upper Midwest (Schulte and others 2007), pines (*Pinus* spp.) in two, and tamarack (*Larix laricina* (Du Roi) K. Koch) in one. Notably, northern white-cedar (*Thuja occidentalis* L.) and balsam fir (*Abies balsamea* (L) Mill) increased in two ecoregions and spruces (*Picea* spp.) in one (Fig. 3). In general, deciduous taxa (especially aspens and maples) exhibited the greatest increase in dominance, while coniferous taxa (especially pines) experienced the greatest decline. Increases in dominance have occurred primarily among shade-tolerant, fire-sensitive taxa (e.g., maple, American basswood, balsam fir), and decreased among species that are shade-intolerant or mid-tolerant and dependent on fire (e.g., aspens, pines). The largest increase in shade-tolerant, fire-sensitive taxa was in Pine Moraines and Outwash Plains and least in Seney Lake Plain (Figs. 3, 4). Conversely, fire-dependent tree taxa, especially pines, declined most profoundly in Pine Moraines and Outwash Plains and least in Seney Lake Plain (Fig. 4).

Table 3 Landscape metrics by refuge based on National Land Cover Data (2001) for only forests

Refuge and forest cover type	Patch density (#/100 ha)	Landscape Shape Index	Mean Patch Area (ha)	Largest Patch Index (%)
Seney NWR				
Deciduous Forest	0.57	25.03	4.66	0.39
Evergreen Forest	2.65	65.53	2.85	0.65
Mixed Forest	0.71	29.58	0.93	0.02
Woody Wetlands	3.10	130.05	14.52	21.85
Tamarac NWR				
Deciduous Forest	1.33	41.93	41.44	47.85
Evergreen Forest	3.67	49.99	2.40	0.64
Mixed Forest	0.06	5.41	0.57	0.01
Woody Wetlands	1.08	25.34	1.82	0.14
Rice Lake NWR				
Deciduous Forest	1.79	20.86	24.15	21.58
Evergreen Forest	1.01	15.53	1.10	0.18
Mixed Forest	0.04	2.63	0.48	0.01
Woody Wetlands	2.05	22.59	2.64	0.55
Kirtland's Warbler WMA				
Deciduous Forest	1.31	8.82	1.51	0.43
Evergreen Forest	5.47	15.54	7.04	4.19
Mixed Forest	3.67	16.30	0.99	0.26
Woody Wetlands	1.57	9.70	3.95	2.71

See Table 1 for a definition of landscape metrics. All metrics other than patch density are indicators of landscape fragmentation

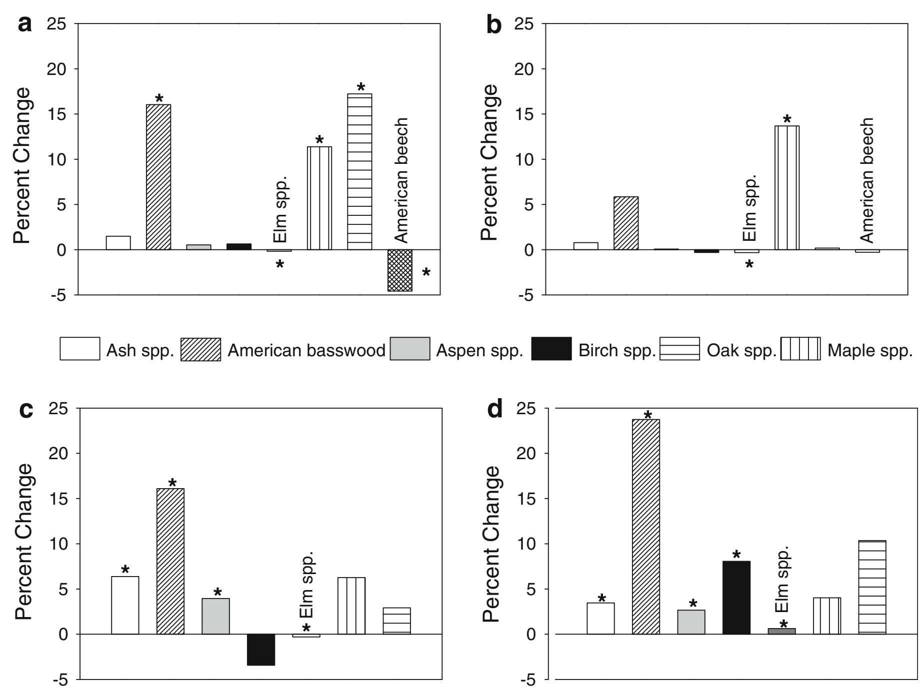

Fig. 3 Percent change in the dominance of broadleaf tree taxa in four ecoregions of study (associated refuges): **a** Kirtland's Warbler High Sand Plains, **b** Seney Lake Plain, **c** St. Louis Moraines, **d** Pine Moraines and Outwash Plains. An "*" indicates that the degree of change observed in a given ecoregion for a given tree taxon is greater than observed in the overall Upper Midwest study area of Schulte and others (2007)

Forest Landbirds of Conservation Priority

Fifteen forest-dependent USFWS Conservation Priority landbird species were identified across the four refuges (Table 4). Kirtland's Warbler WMA was characterized by a simple, five-species Priority bird community, whereas the three remaining refuges had larger (although markedly similar) Priority bird communities. Late-successional

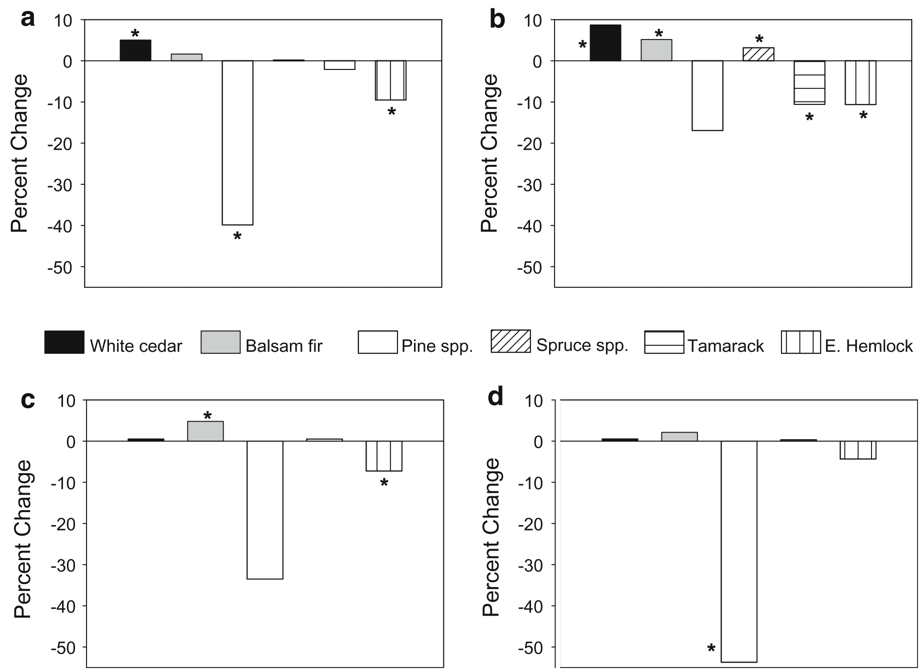

Fig. 4 Percent change in dominance of coniferous tree taxa in four ecoregions of study (associated refuges): **a** Kirtland's Warbler High Sand Plains, **b** Seney Lake Plain, **c** St. Louis Moraines, **d** Pine Moraines and Outwash Plains. An "*" indicates the magnitude of change observed in a given ecoregion for a given tree taxon is greater than observed in the overall Upper Midwest study area of Schulte and others (2007)

(mature) forests were identified as primary breeding habitats for eight species (northern goshawk, *Accipiter gentilis* L.; red-shouldered hawk, *Buteo lineatus* Gmelin; olive-sided flycatcher, *Contopus cooperi* Swainson; wood thrush, *Hylocichla mustelina* Gmelin; cerulean warbler, *Dendroica cerulea* Wilson; Canada warbler, *Wilsonia canadensis* L.; Connecticut warbler, *Oporornis agilis* Wilson; and black-throated blue warbler, *Dendroica caerulescens* Gmelin). Five species primarily used early-successional forests (American woodcock; black-billed cuckoo, *Coccyzus erythropthalmus* Wilson; whip-poor-will, *Caprimulgus vociferus* Wilson; golden-winged warbler, and Kirtland's warbler) and two species utilized forests of different successional stages (northern flicker, *Colaptes auratus* L.; Cape May warbler, *Dendroica tigrina* Gmelin). Deciduous forests were used by nine species, six species used evergreen (coniferous) forests, four species utilized mixed forests, and three species were not identified to any specific forest type (Table 4). Our literature review allowed us to characterize area sensitivity for only eight of the 15 species, five of which (red-shouldered hawk, wood thrush, cerulean warbler, Canada warbler, and black-throated blue warbler) were associated with mature forests. Only two area-sensitive species were associated with young forests (black-billed cuckoo and whip-poor-will; Table 4).

Discussion

Placing landscape dynamics and patterns into the context of their ecoregional-scale surroundings provides a basis for the strategic prioritization of conservation and restoration efforts at multiple levels of biological organization. Moreover, understanding ecological drivers at ecoregional scales provides a foundation for planning and management in protected areas (e.g., refuges). Within our study landscapes (refuges) and ecoregions our findings highlight: (1) the implications of land use and land cover for the ecological function of protected areas; (2) ecological processes (e.g., fire) that may be operating at larger spatial scales; and (3) tradeoffs between species protection and other human uses (Thomas 1996; Christensen and others 1996, Wiens 2009). As such, our findings provide an important, evidence-based approximation for priority-setting on forested wildlife refuges (Cook and others 2010).

In many parts of the country where public land ownership occurs in large, contiguous blocks, land managers have opportunities to manage important ecological processes such as fire that will meet ecosystem-based goals and objectives (Wilson and others 2009). The four refuges in this study provide the opportunity to develop coarse- and meso-filter conservation strategies (Hunter 2005) that focus on natural disturbances and vegetation patterns for forest wildlife habitat because the surrounding ecoregions contained a high proportion of public land. Private conservation partners in forest habitat management are not to be overlooked, however; Rice Lake NWR and Tamarac NWR were found in ecoregions dominated by private lands. The configuration of private and public land in these ecoregions may allow for the conservation of bird species that rely on tree species that have increased in dominance over the last century (such as aspen) on private land, while restoring the natural balance of fire-tolerant and sensitive communities by restoring ecological processes such as fire to public land.

Table 4 U.S. Fish and Wildlife Service Midwest Region Conservation Priority forest landbird species (USFWS 2002) by general breeding forest habitat type(s) used at refuges of study and minimum patch size for area-sensitive species (Robbins and others 1989)

Common name	Scientific name and author	General forest habitat(s) used	Minimum patch size for area-sensitive species (ha)	Kirtland's Warbler WMA	Seney NWR	Rice Lake NWR	Tamarac NWR
Northern goshawk	*Accipiter gentilis* L.	Range of mature forest types with large trees for stick nests			x	x	x
Red-shouldered hawk[a–s]	*Buteo lineatus* Gmelin	Mature deciduous and mixed riparian forests	>100		x	x	x
American woodcock	*Scolopax minor* Gmelin	Young stands of primarily deciduous forests		x	X	X	X
Black-billed cuckoo[na-s]	*Coccyzus erythropthalmus* Wilson	Young evergreen (coniferous) or deciduous forests		X	X	x	X
Whip-poor-will[na–s]	*Caprimulgus vociferus* Wilson	Young evergreen (coniferous) or deciduous forests		X	X	x	x
Northern flicker[na-s]	*Colaptes auratus* L.	Generally ubiquitous, but in need of standing dead trees		X	X	X	X
Olive-sided flycatcher	*Contopus cooperi* Swainson	Range of mature forests with prominent trees/snags			X	X	x
Wood thrush[a–s]	*Hylocichla mustelina* Gmelin	Generally mature deciduous or mixed forests	>10		x	X	X
Golden-winged warbler	*Vermivora chrysoptera* L.	Young deciduous or wet evergreen (coniferous) forests			x	X	X
Cerulean warbler[a–s]	*Dendroica cerulea* Wilson	Mature deciduous riparian forests	>100		x		X
Connecticut warbler	*Oporornis agilis* Wilson	Mature wet evergreen (coniferous) forests			x	X	X
Kirtland's warbler	*Dendroica kirtlandii* Baird	Young evergreen (coniferous) forests		X			
Canada warbler[a–s]	*Wilsonia canadensis* L.	Mature deciduous or mixed forests	>10		x	X	
Black-throated blue warbler[a–s]	*Dendroica caerulescens* Gmelin	Mature deciduous or mixed forests	>100		x	x	
Cape May warbler	*Dendroica tigrina* Gmelin	Wet evergreen (coniferous) forests			x	x	

An "X" signifies a species that is consistently found from year to year during the breeding season on refuge lands, an "x" signifies a species that is infrequently found during the breeding season. Empty cells signify a species that is not found or whose presence is unknown. Not shown are species that utilize openland conditions created by major forest disturbances such as clearcuts or wildfire. Species common names with a superscript "a–s" are those identified as being area-sensitive. Species with a superscript "na–s" are those identified as not being area-sensitive. Area sensitivity of remaining species is undetermined

Our analysis of land cover patterns at the ecoregional scale has a number of conservation and restoration implications with regard to the refuges as restoration sites and "refugia" for wildlife. Most differences in land cover proportions between refuge and ecoregion resulted from a disproportionate amount of some land cover types that were specifically conserved or even anthropogenically increased to provide wildlife habitat on refuges. Both Rice Lake NWR and Tamarac NWR included a disproportionate amount of emergent herbaceous vegetation beneficial for waterfowl compared to their associated ecoregions. Seney NWR was dominated by wetland ecosystems and had many large open water patches due to anthropogenic pools created for waterfowl. Kirtland's Warbler WMA lacked deciduous forest and woody wetlands common to the ecoregion, but not useful to Kirtland's warbler conservation (Fig. 2). Nevertheless, all refuges exhibited larger average patch sizes than their associated ecoregions and more aggregated patches. These findings indicate that, as hoped, refuges may have conditions better suited for conserving Priority bird species with known area sensitivities and correspondingly more interior habitat area relative to edge habitat area compared to surrounding ecoregional lands (Table 2).

Refuges examined in this study had up to five times as much forested area as most refuges in the contiguous United States (Scott and others 2004), highlighting their importance for the representation of specific forest types within the entire NWRS. Moreover, except as noted above, the four refuges we studied exhibited relatively low contrast in landscape composition between refuge and ecoregion. Similarity in forest composition between refuge and ecoregion suggests parallel changes in forests at both spatial scales over the last century, however, and thus refuges are not necessarily representative of pre-Euro-American forest conditions (Schulte and others 2007; Drobyshev and others 2008b; Figs. 2, 3). Nevertheless, broad objectives in the NWRS of habitat provision rather than timber production or motorized recreation suggest ample opportunities for management activities that focus on ecological restoration of forests as well as conservation of wildlife habitat on these lands.

Land use change and associated changes in disturbance regimes and related ecological processes are likely strong drivers of the altered conditions we describe for both ecoregions and refuges. Extensive timber harvesting near the turn of the twentieth century and altered fire regimes have been associated with compositional changes in the pine-dominated Seney Lake Plain (Drobyshev and others 2008a, b). Likewise, declines in other coniferous taxa (especially tamarack) in the Seney Lake Plain ecoregion are related to anthropogenic changes in hydrology, as this area was ditched for agricultural purposes, then diked for waterfowl habitat in the 1930s and 1940s (Losey 2003). In addition, anthropogenic-related increases in populations of white-tailed deer (*Odocoileus virginianus* Zimmermann) and their associated browsing have altered forest composition across the entire Upper Midwest region, including the refuges and ecoregions herein studied (Rooney 2001). For example, we noted significant increases in some taxa considered to be unfavorable deer browse (e.g., balsam fir and American basswood) in the St. Louis Moraines and Pine Moraines and Outwash Plains (Figs. 2, 3), although taxa favored by deer (maples) decreased inconsistently across the four ecoregions (Figs. 2, 3). Finally, exotic forest insects and pathogens will create impending losses of American beech due to the beech bark disease complex and ash species due to emerald ash borer (*Agrilus planipennis* Fairmaire) though impacts will be disproportionate across ecoregions based on current forest composition.

Despite having relatively larger patches of wildlife habitat, the refuges examined in this study contain surprisingly few suitable forest habitat patches in their current configuration. For example, our analysis suggests that at least 3 of the 15 Priority forest landbird species found on the four refuges require a minimum patch size of deciduous or mixed forest of >100 ha (Table 4); only six patches met this criteria at Rice Lake NWR (largest three patches are 1760, 560, and 330 ha), five at Tamarac NWR (largest patches 8500 and 350 ha), and two at Seney NWR (150 and 124 ha). At least two species require patches of deciduous or mixed forest >10 ha, with 17 found at Seney NWR, 15 at Tamarac NWR, and 12 at Rice NWR. If the patches >10 times the mean size of the other patches are excluded as outliers, most refuge patches are too small to provide habitat for area-sensitive birds. More consideration for managing increased patch sizes is therefore needed if management on refuges is to benefit many Priority forest landbird species. This finding provides further support to those of Crozier and Niemi (2003), who found that small patch sizes at the naturally heterogeneous Seney NWR limited the abundance of many forest bird species.

Management Implications

The unique and beneficial forest composition and landscape patterns found in refuges we studied might be managed to conserve or restore forest biodiversity as well as to protect migratory bird habitat in a manner specific to the ecoregion they are located in. Management in this vein would vary among refuges based on the ecoregional context of each refuge, but overall might focus on less common forest types in larger patches and/or rarer compositional or structural attributes. The relatively small proportion of ecoregion area designated as refuges (ca. 2%) makes multi-scaled assessments and partnerships all the more critical because refuges by themselves cannot be expected to conserve or restore all ecoregional biodiversity. For example, the similarity of Seney NWR to its ecoregion and the large proportion of public land in its ecoregion would facilitate the extensive use of prescribed or managed wildfire to restore rare forest types or components. At Rice Lake NWR and Tamarac NWR, whose ecoregions contain less public land, management may instead focus on management for rarer late-successional forest types declining in the ecoregion while working with private partnerships to manage for early successional forest in the ecoregion. See Table 5 for specific refuge-scale management recommendations based on this study.

Table 5 Refuge-scale recommendations for four refuges in the Upper Midwest based on an analysis of landscape pattern of forests in the refuges and their associated ecoregions

Refuge	Summary and management recommendations
Seney NWR	The refuge represents the diversity of forest types found in its ecoregion well, and overall is very similar to the ecoregion as a whole. The large area of public land ownership suggests the extensive use of prescribed or managed wildfire to restore rarer forest types (e.g., mixed-pine) or compositional attributes (e.g., scattered pine in hardwoods) is possible. Area sensitive birds would benefit from management that increased mean patch size.
Tamarac NWR	The refuge represents diversity of ecoregional patch types well, and is less fragmented than the ecoregion. A regionally appropriate management focus for the refuge may be to restore rarer, late-successional forest types or compositional attributes (e.g., scattered pine in hardwoods), given the regional declines of these types and attributes. The refuge has opportunity to work with the abundant private land owners to manage early successional forests for forest landbird species of conservation priority (e.g., American woodcock, golden-winged warbler). Emerald ash borer may be a considerable threat to its hardwood forests, but mortality could be used to proactively introduce white pine in these gaps.
Rice Lake NWR	Relative to its ecoregion, the refuge is composed of fewer patch types and is less fragmented. Similar to Tamarac NWR, the refuge could focus management on restoring rarer, late-successional forest types or compositional attributes (e.g., scattered pine in hardwoods) and work with the abundant private land owners to manage early successional forests for forest landbird species of conservation priority (e.g., American woodcock, golden-winged warbler). Emerald ash borer may be a considerable threat to its hardwood forests, but mortality could be used to proactively introduce white pine in these gaps.
Kirtland's Warbler WMA	The WMA seems well positioned to focus on Kirtland's warbler habitat, but the small size of pine-dominated forest patches precludes the extensive use of prescribed fire or managed wildfire, although fire is an essential ecological disturbance of xeric pine ecosystems.

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Appendix 1: Tree taxa used in this study

Deciduous species	Coniferous species
American basswood (*Tilia americana* L.)	Balsam fir (*Abies balsamea* (L) Mill.)
American beech (*Fagus grandifolia* Ehrh.)	Eastern hemlock (*Tsuga canadensis* (L.) Carriere)
American hornbeam (*Carpinus caroliniana* Walter)	Jack pine (*Pinus banksiana* Lamb.)
Black ash (*Fraxinus nigra* Marsh.)	Red pine (*P. resinosa* Sol.)
Green ash (*F. pennsylvanica* Marsh.)	White pine (*P. strobus* L.)
White ash (*F. americana* L.)	Black spruce (*Picea mariana* Mill.)
Balsam poplar (*Populus balsamifera* Rehder)	White spruce (*P. glauca* (Moench) Voss)

Appendix continued

Deciduous species	Coniferous species
Eastern cottonwood (*P. deltoids* Marsh.)	Tamarack (*Larix laricina* K. Koch)
Bigtooth aspen (*P. grandidentata* Michx.)	Northern white cedar (*Thuja occidentalis* L.)
Trembling aspen (*P. tremuloides* Michx.)	
Paper birch (*Betula papyrifera* Marsh.)	
Yellow birch (*B. alleghaniensis* Britt.)	
Black cherry (*Prunus serotina* Ehrh.)	
Choke cherry (*P. virginiana* L.)	
Pin cherry (*P. pensylvanica* L.)	
American elm (*Ulmus americana* L.)	
Rock elm (*U. thomasii* Sarg.)	
Slippery elm (*U. rubra* Mulh.)	
Hop-hornbeam (*Ostrya virginiana* (Mill) K. Koch)	
Mountain maple (*Acer spictatum* Lamb.)	
Red maple (*A. rubrum* L.)	
Silver maple (*A. saccharinum* L.)	
Sugar maple (*A. saccharum* Marsh.)	
Black oak (*Quercus velutina* Lamb.)	
Bur oak (*Q. macrocarpa* Michx.)	

Appendix continued

Deciduous species	Coniferous species
Northern pin oak (Q. *ellipsoidalis* E.J. Hill)	
Pin oak (*Q. palustris* Muenchh.)	
Northern red oak (*Q. rubra* L.)	
Swamp white oak (*Q. bicolor* Willd.)	
White oak (*Q. alba* L.)	
Butternut (*Juglans cinerea* L.)	

Appendix 2. National Land Cover Data (NLCD 2001) class definitions for land covers found covering >10% of the area of refuges and ecoregions of study

Deciduous Forest: Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen Forest: Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.

Woody Wetlands; Areas where forest or shrubland vegetation accounts for >20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Shrub-Scrub: Areas dominated by shrubs; >5 m tall with shrub canopy typically >20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

Herbaceous: Areas dominated by herbaceous vegetation, generally >80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

Emergent Herbaceous Wetlands: Areas where perennial herbaceous vegetation accounts for >80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Open Water: Areas of open water, generally with <25% cover of vegetation or soil.

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