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Spatial characteristics of early successional habitat across the Upper Great Lakes states

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ABSTRACT

Creation and management of early successional forest (ESF) is needed to halt and reverse declines of bird species dependent on pioneering plant species or young forests. ESF-dependent bird species require specific structural forest classes and are sensitive to forest age (a surrogate for forest structure), patch size, proximity to patch edges, and the juxtaposition of forest age classes. To date, ESF conservation plans have relied on spatially inexplicit data, lacking patch and landscape metrics, to set habitat goals and to track habitat trends. In a previous study, we used Landsat time series stacks and a vegetation-change-tracker algorithm to track forest canopy disturbances and subsequent regrowth from 1990 to 2009 across the Upper Great Lakes Young Forest Initiative region. Based on canopy disturbance histories, we assigned forest age classes to forest classes of the National Land Cover Database of 2011. In the present study, we used this spatial product to assess areas, patch and edge metrics, and land protection statuses of deciduous-mixed forest and woody wetland age classes. We defined ESF using four 5-year-age classes (1–5, 6–10, 11–15, 16–20 years old) and their aggregate (1–20 years old) whereas forest >20 years old was referred to as 'persisting'. Aggregated across 5-year-age classes, ESF of deciduous-mixed forest covered 3.4% and 0.9% of Bird Conservation Regions (BCR) 12 (Boreal Hardwood Transition) and 23 (Prairie Hardwood Transition), respectively, whereas woody wetland ESF constituted 1.0% and 0.2% of the same BCRs. For both deciduous-mixed forest and woody wetlands, ESF often occurred in patches $\geqslant$1 ha, but most ESF also occurred near patch edges created by adjacencies with persisting forest. Most ESF fell on lands with an unprotected or unknown protection status regardless of forest class. Regionally, ESF covered less area, occurred in smaller patches and nearer to edges, and more often fell on lands of unprotected or unknown protection status in BCR 23 than in BCR 12. Our results advance ESF conservation by providing insight into spatial characteristics that influence habitat quality and by establishing a baseline for habitat management planning and monitoring.

1. Introduction

Early-successional forest (ESF), defined here to include areas dominated by either pioneer plant species or young forest (Lorimer, 2001), is used by many bird species at different times during their annual cycles (Schlossberg and King, 2008; Streby et al., 2011). Disrupted natural disturbance regimes (e.g., fire suppression), changing timber management practices (e.g., uneven-aged forest management), and land-use conversion (e.g., forest to urban) have contributed to long-term declines in abundance of ESF and ESF-associated bird species in several sub-regions of the eastern U.S. (Trani et al., 2001; King and Schlossberg, 2014). To stabilize and restore populations of ESF-dependent bird species, natural resource managers require information about the amount, distribution, and trends of ESF to create habitat management plans and to evaluate their successes.

Linkages between birds and vegetation associations, such as ESF, defined by plant species composition, successional stage, or structure can be used for regional bird habitat assessments (Trani et al., 2001; Beaudry et al., 2010), but habitat is not synonymous with vegetation associations (Hall et al., 1997). Regional habitat assessments can be refined by applying constraints representing specific habitat requirements at local (e.g., sapling height), patch (e.g., patch size), and landscape (e.g., proximity of forest and old fields) scales (Dwyer et al., 1983; Beaudry et al., 2010). ESF-dependent bird species respond to forest age classes (Schlossberg

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and King, 2009) associated with specific structural characteristics, the juxtaposition of forest age classes (e.g., Streby et al., 2015), forest patch sizes (e.g., Annand and Thompson, 1997), and proximity to patch edges (e.g., Fink et al., 2006). One example of forest composition and age class association is provided by the Canada Warbler (*Cardellina canadensis*), a species preferring 6–20-year-old deciduous or mixed forests with exposed song perches and well-developed understories as breeding habitat (Hagan et al., 1997; Reitsma et al., 2010). ESF-dependent bird species, such as the Golden-winged Warbler (*Vermivora chrysoptera*), might also use multiple forest age classes to meet life history needs (e.g., Streby et al., 2015), and thus, benefit from the juxtaposition of age classes.

Based on a literature review, Schlossberg and King (2007) suggested that scrub–shrub birds might be absent or less abundant in patches less than 1 ha in size whereas they might be insensitive to increasing patch size beyond 4 ha. Scrub–shrub habitat was defined as areas possessing no or little tree canopy and dense shrubs and saplings within the first 2 m above ground and included, e.g., ESF created through even-aged forest management (Schlossberg and King, 2007). The same researchers conducted a meta-analysis and found that several scrub–shrub bird species had higher abundances in clearcut interiors (>60 m from edge) than near edges between clearcuts and mature forests (<30 m from edge) (Schlossberg and King, 2008). Failure to account for forest age class, age class juxtaposition, patch size, or proximity to edge effects will lead to overestimates of habitat area available to ESF-associated bird species and biased assessments of progress toward meeting habitat management goals. For example, tree canopy disturbances may increase ESF area, but the value of this habitat to American Woodcock (*Scolopax minor*) may be reduced if it abuts urban areas, a cover class shown to be negatively correlated with the abundance of male woodcocks (Dwyer et al., 1983).

Managers often lack information to simultaneously address local, patch, and landscape features over large spatial extents and long periods for bird species (Tirpak et al., 2009; Beaudry et al., 2010). The USDA Forest Service's Forest Inventory and Analysis (FIA) program, a national-level inventory and monitoring program, reports detailed information on forest composition and structure (Woudenberg et al., 2010). This information can be used to assess forest habitat classes and microhabitat conditions from as far back as the 1960's to present day for much of the U.S. Nevertheless, FIA sample and plot designs do not provide spatially explicit data regarding forest patch or landscape characteristics (e.g., patch adjacency) (Woudenberg et al., 2010).

With respect to spatially explicit data, our assessment of ESF requires data on all of the following characteristics: forest composition classes and nonforest land cover classes, structural stages spanning 1–20 years of forest age, spatially explicit patches as small as 1 ha, and distances to edge as short as 30 m; thus, a geospatial dataset having 30-m spatial resolution or finer is required to address ESF patch and landscape characteristics. The following paragraph provides a brief summary of the predominant, nationally-available, geospatial datasets that address one or more, but not all of the ESF characteristics for bird species.

The National Land Cover Database of 2011 (NLCD2011) (Homer et al., 2015) is a moderate spatial resolution (30-m) data set that permits patch and landscape metrics to be quantified for forest compositional classes (e.g., deciduous, evergreen, and mixed forest). However, NLCD2011 does not attribute woody wetlands with forest compositional classes, nor does it include information about forest age or related structural attributes (e.g., tree diameter, height) important to defining ESF habitat. The LANDFIRE program makes available a 30-m spatial resolution product that maps year of forest disturbance during the fourteen year period, 1999–2012 (LANDFIRE, 2012), but this product omits ESF of 15–20 years of age. The National Biomass and Carbon Dataset (NBCD; Kellndorfer et al., 2004) provides a 30-m geospatial data set of basal area-weighted canopy height as of the year 2000, from which structural characteristics (and possibly stand age) can be inferred, but NBCD omits ESF that originated after 2000. Forest stand age data are available from Pan et al. (2011), but the coarser spatial resolution associated with this dataset (250 m or 1 km) is inappropriate for analyzing small patches and edge distances. A nationwide 30-m geospatial dataset of forest disturbance is available for the period 1986–2010 (Goward et al., 2015), but this dataset does not include attributes of forest composition. We are unaware of any single geospatial dataset for the western Great Lakes region that simultaneously captures forest composition, age, patch, and landscape metrics at 30-m spatial resolution.

The Upper Great Lakes Young Forest Initiative (YFI) is working to stabilize and eventually increase the amount of ESF habitat found in Bird Conservation Regions (BCR) 12 (Boreal Hardwood Transition) and 23 (Prairie Hardwood Transition) within the states of Michigan, Wisconsin, and Minnesota, USA. YFI is intended to benefit a broad suite of wildlife species dependent on ESF habitat. Its current habitat goals are derived from the American Woodcock Conservation Plan (Cooper, 2008; Kelley et al., 2008) and have as a fundamental objective restoring American Woodcock densities to those observed during the early-1970s (Cooper, 2008; Kelley et al., 2008). Updates to YFI habitat goals are dependent on new input provided by cooperators and an improved understanding of species' habitat needs. Evolution of the YFI habitat goals will be aided by the development of species-specific plans and habitat goals, such as those recently released for the Golden-winged Warbler (Roth et al., 2012).

To further inform future YFI planning efforts, our objective was to use a novel spatial data set to quantify total area, juxtaposition, patch size, and proximity to patch edges of ESF age classes at different spatial scales and temporal intervals. These spatial features are applicable to a broad suite of ESF-dependent species rather than being species-centric (Hunter et al., 2001; Schlossberg and King, 2007, 2008). We also assessed the occurrence of ESF age classes on lands with different conservation protection statuses, and we used these data to suggest future opportunities for ESF creation and maintenance. Our assessment establishes a baseline of ESF conditions for management planning and for monitoring progress toward management goals with the ultimate objective of stabilizing and growing ESF-limited bird populations.

2. Methods

2.1. Study region description

The YFI region includes the U.S. portions of BCRs 12 and 23 that fall within the states of Michigan, Minnesota, and Wisconsin (Fig. 1). BCRs are defined based on shared bird communities, habitats, and natural resource management issues (Matteson et al., 2009). The American Woodcock is a popular game bird throughout the region, and other priority, ESF-dependent bird species common to both BCRs include Golden-winged Warbler, Field Sparrow (*Spizella pusilla*), and Black-billed Cuckoo (*Coccyzus erythropthalmus*) (Knutson et al., 2001; Matteson et al., 2009). BCR 12 contains coniferous and northern hardwood forests, nutrient-poor soils, and many lakes, bogs, and other water bodies formed through river overflows (U.S. NABCI Committee, 2000). Following European settlement, anthropogenic influences have resulted in the exploitation of timber and natural resources, conversion of land for agricultural purposes, wetland loss, reduced tree species richness, and some urbanization (Matteson et al., 2009). Historically, BCR 23 transitioned from prairies in the west and south to beech-maple forests in the north and east, and oak savannas occurred

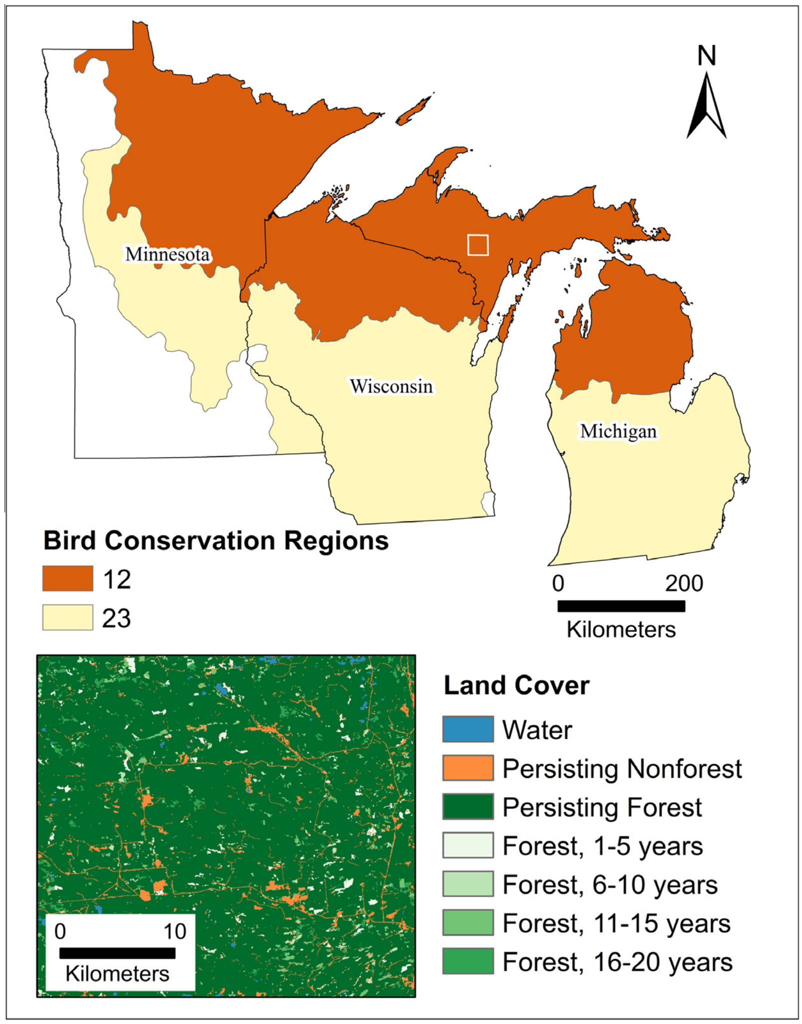

Fig. 1. Upper Great Lakes Young Forest Initiative region (top). The region consists of Bird Conservation Regions 12 and 23 within the states of Michigan, Wisconsin, and Minnesota, USA. For a small area (delineated by white box in northern Michigan), the inset map (bottom) displays forest age classes based on date of last canopy disturbance derived from a Landsat time series stack. We intentionally chose a heavily forested landscape with relatively abundant disturbances to reveal patterns contained in the data. Persisting forest refers to stands >20 years old.

between these two habitat types (U.S. NABCI Committee, 2000). Currently, BCR 23 is dominated by agricultural land-use and includes several major urban centers (Knutson et al., 2001). Once, a variety of disturbance forces, including windstorms, fire, drought, insect and disease infestations created and maintained ESF in this region (Lorimer, 2001; Stueve et al., 2011a). With the suppression of some natural disturbance regimes (e.g., fire) in the region, ESF is now dependent primarily on forest harvest and management guided by established best management practices (Trani et al., 2001; Wildlife Management Institute, 2009); 65% of 1–5 year-old forest on timberland was associated with tree harvest activities in Michigan, Wisconsin and Minnesota during the period 2005–2009 (Miles, 2015).

2.2. ESF geospatial layer

We used a novel spatial research dataset (RDS) that enhanced NLCD2011 (Homer et al., 2015) by assigning age classes to deciduous, evergreen, mixed and woody wetland forest classes (Garner et al., 2015, 2016). The RDS was the result of integrating NLCD2011 with a forest age map produced through the application of a vegetation-change-tracker algorithm (VCT; Huang et al., 2010) with a winter-imagery-enhancement (VCTw; Stueve et al., 2011b) (Fig. 1) to time series of Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus images (Garner et al., 2016). VCTw uses temporal changes in spectral data from the Landsat Time Series Stack (LTSS) to detect forest canopy disturbances and subsequent regrowth, and these data are used to predict year of most recent canopy disturbance and forest age for pixels in the images. Our LTSS included approximately biennial images from 1987 to 2010 (Garner et al., 2015). An additional forest class was created and labeled as 'other forest' for pixels where NLCD2011 class was either shrub/scrub or grassland/herbaceous and the spatially corresponding VCTw-based age map was classified as forest. This was done to address potential omission of ESF from NLCD2011 due to confusion with the grassland/herbaceous class following substantial tree canopy disturbance, and with the shrub/scrub class during a period of tree regeneration. The RDS possessed a spatial resolution of 30 m, matching the resolution of NLCD2011.

Forest disturbances from the period 1990–2009 that exhibited subsequent regrowth were classified into one of four age classes (1–5, 6–10, 11–15, 16–20 years old), inversely corresponding to four 5-year intervals (1990–1994, 1995–1999, 2000–2004, 2005–2009) (Garner et al., 2015). These age classes or their aggregation (1–20 years old) defined ESF in this study. We assumed that post-disturbance recovery of the upper canopy after 20 years eliminates habitat features (e.g., shrubs or herbaceous vegetation) important to ESF-dependent birds, and we note that other researchers have made a similar assumption (e.g., Schlossberg and King, 2009). Forest undisturbed during the period was assigned to a single class of >20 years and is referred to as 'persisting forest'. A minimum mapping unit (MMU) was applied to the RDS such that cover class patches smaller than 4 pixels (0.36 ha) were dissolved into an adjacent patch. We applied the MMU to reduce effects of image misregistration and to match the definitions with FIA data (n = 27,219 FIA plots) that were used for validation assessments within the YFI per "good practices" in Olofsson et al. (2014). Given its size, the MMU did not result in the elimination of ESF patches ⩾1 ha, the patch size threshold suggested as potentially important for bird habitat use (Schlossberg and King, 2007; Shake et al., 2012). The RDS is clipped to the borders of the YFI; therefore, we used an unclipped version of the RDS (unpublished) that encompasses all Landsat Path/Rows that intersected the region within the contiguous U.S. This expanded geographic extent minimized potential errors when calculating patch metrics for patches not fully contained in the study area.

Overall classification accuracy for the RDS was 84.9% (±0.42%, based on 95% confidence intervals) for seven thematic classes (Persisting forest, Forest disturbed 1990–1994, Forest disturbed 1995–1999, Forest disturbed 2000–2004, Forest disturbed 2005–2009, Nonforest, and Water). Each of the four 5-year age classes comprised less than 1% of the study area, and their corresponding accuracies were low, ranging from 15 to 31% for producer's accuracies and 39–45% for user's accuracies (Garner et al., 2015). Garner et al. (2015) and Section 4 provide explanations for the seemingly low accuracies of the 5-year age classes.

Modifications of the RDS were carried out in the geographic information system ArcMap 10.2.2 (ESRI, Redlands, California). For our analyses, we aggregated NLCD2011 deciduous and mixed forest cover classes into a single class called deciduous-mixed forest. We elected to aggregate these two classes as breeding American Woodcock (Keppie and Whiting, 1994) and other species of conservation concern (e.g., Canada Warbler, Reitsma et al., 2010) can use either deciduous or mixed forest types. We retained woody wetlands as a separate class to assess the juxtaposition of woody wetlands and deciduous-mixed forests. Woodcock prefer moist soil for foraging whereas other activities (e.g., nesting) occur in upland areas (Keppie and Whiting, 1994). Further, some ESF-dependent songbird species prefer uplands to wetlands (Chandler et al., 2009), further emphasizing the need to distinguish between deciduous-mixed forests and woody wetlands. The evergreen class was too thematically coarse to resolve habitat for the Kirtland's Warbler (*Setophaga kirtlandii*), a federally endangered species, that is dependent on young jack pine (*Pinus banksiana*) (Bocetti et al., 2014). In addition, evergreen forest is generally unused by woodcock (Keppie and Whiting, 1994). For these reasons, we do not report patch or landscape metrics for the evergreen forest class, but it was retained as a separate class for potential analysis in other studies.

No forest type attribution was available for NLCD2011 shrub/scrub and grassland/herbaceous patches that were reclassed as 'other forest' patches (as described above); therefore we used a nearest neighbor approach to attribute 'other forest' pixels with the dominant type class of adjacent forest pixels – either deciduous-mixed or evergreen forest classes. In using the nearest neighbor approach, we assumed that 'other forest' pixels were likely to be of the same thematic class as neighboring forest pixels. A similar assumption was made during the creation of the RDS as narrow strips of unattributed pixels were assigned an age class based on their nearest neighbors (Garner et al., 2015). Among nonforest classes, we aggregated NLCD2011 classes of developed open space, developed low intensity, developed medium intensity, and developed high intensity into a single developed class, and we lumped pasture/hay and cultivated crops into a single agriculture class.

2.3. Land cover and forest age class areas, patch, and landscape metrics

We quantified a set of readily interpretable metrics linked to habitat abundance and quality for ESF-associated wildlife species. Spatial analyses were carried out with ArcMap 10.2.2 whereas statistical analyses were completed in the program R 3.1.2 (R Core Team, 2014). For each age class of deciduous-mixed forests and woody wetlands, we assessed total area, percentages of shared edges with other age and cover classes as a measure of juxtaposition, percentage occurring in patches ⩾1 ha, and percentage of core area (⩾60 m from a patch edge) (Schlossberg and King, 2008) as an inverse measure of proximity to patch edges. We defined a patch as a group of pixels sharing the same cover and age classes and being adjacent to one another. Estimates of area were obtained by multiplying pixel count for a given patch or class times 900 m^2 (area of a single 30-by-30-m pixel). Given the mobility of birds and the resolution of our data set, we considered pixels to be adjacent to one another if they shared a side or a single corner. We defined a shared edge as the linear boundary between two pixels that differed in age or cover classes. The edge of a patch consisted of all such linear boundaries that circumscribed a patch.

For each age class of deciduous-mixed forests and woody wetlands, percentage of shared edges was:

$$S_j = E_j / \sum_{j=1}^{n} E_j \times 100 \quad (1)$$

where S_j was the percentage of shared edges between an age class and another age or cover class j, E_j was the number of shared edges between pixels of an age class and another age or cover class j, and n was the total number of age and cover classes adjacent to an age class. We determined the percentage of habitat occurring in patches ⩾1 ha in size as:

$$P_{ha} = A_{ha} / A_{total} \times 100 \quad (2)$$

where P_{ha} was percentage of area in patches ⩾1 ha for an age class, A_{ha} was area in patches ⩾1 ha for the age class, and A_{total} was the total area of the age class across all patches regardless of patch size. We selected the 1 ha minimum threshold based on Schlossberg and King (2007) and Shake et al. (2012). Calculation of percentage of core area was:

$$P_{core} = A_{core} / A_{total} \times 100 \quad (3)$$

where P_{core} was percentage of core area (⩾60 m from a patch edge; Schlossberg and King, 2008) for an age class, and A_{core} was the core area of the age class.

We also reported areas of deciduous-mixed forests and woody wetlands age classes partitioned by four protection statuses, using a geospatial dataset derived by the Conservation Biology Institute (Foster et al., 2014): "(1) restricted-use lands (GAP Status 1 and 2)", defined as permanently protected lands managed to maintain a natural or nearly natural state; (2) "multiple-use lands (GAP Status 3)", defined as permanently protected lands managed for conservation of predominately natural land cover with multiple uses including some extractive uses; (3) "conservation easements", defined as lands with voluntary restrictions for conservation purposes; and (4) "unknown/unprotected (Gap 4 or Unknown)", defined as land cover for which there are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat to anthropogenic land covers.

We completed the above assessments individually for areas of BCRs 12 and 23 within YFI region. We defined these spatial units using state boundaries ('statep010g' shapefile) from the National Atlas (nationalatlas.gov) and BCR boundaries ('BCR Terrestrial Master' feature class, geodatabase v10) from Bird Studies Canada (bsc-eoc.org). Because our spatial data set is publicly available (Garner et al., 2016), we note that other researchers can use our data set to summarize age classes based on metrics and spatial units tailored to meet their research objectives.

3. Results

3.1. Land cover and forest age class areas

Forest covered approximately three quarters of BCR 12 whereas forest constituted less than a third of BCR 23 (Table 1). In both BCRs, deciduous-mixed forest covered more area than woody wetlands, which, in turn, covered more area than evergreen forests. The persisting age class comprised more than 91% of deciduous-mixed forests and woody wetlands in the two BCRs (Fig. 2). None of the ESF 5-year-age classes or their aggregate made up more than 8.3% of deciduous-mixed forest or woody wetlands in either BCR. Nonforest cover classes for BCR 23 were most often agricultural or developed lands, with agricultural lands comprising more than half of all land cover within BCR 23 (Table 1). Open water and agricultural lands covered the greatest percentages of BCR 12 relative to other nonforest classes, but agriculture covered a much smaller percentage of BCR 12 than BCR 23.

3.2. Shared edges

For both BCRs, shared edges of ESF age classes were dominated by persisting cover of the same forest class, and shared edges between ESF 5-year-age classes were relatively uncommon for deciduous-mixed forests and woody wetlands (Table 2). A small percentage of persisting deciduous-mixed forest and woody wetland edges were adjacent to younger age classes for BCRs 12 and 23 (Table 2). For all age classes of deciduous-mixed forests and woody wetlands, shared edges with forest cover classes were more common in BCR 12 as nonforest edges constituted a relatively large percentage of shared edges in BCR 23 (Table 3). Developed or agricultural lands were the most common nonforest edges with the exception of woody wetland age classes in BCR 12 for which herbaceous wetland edges were dominant. For age classes of deciduous-mixed forests and woody wetlands, developed and agricultural lands represented a greater percentage of shared edges in BCR 23 relative to BCR 12.

3.3. Patch size and core area

More than half of deciduous-mixed forest or woody wetland ESF ($\leqslant$ 20 years old) patches were <1 ha in size within BCR 12, and more than three quarters were <1 ha in BCR 23 (Fig. 3). Despite this fact, relatively large percentages of ESF age classes, by area, occurred in patches $\geqslant$1 ha (Fig. 4). At least 66% and 37% of each

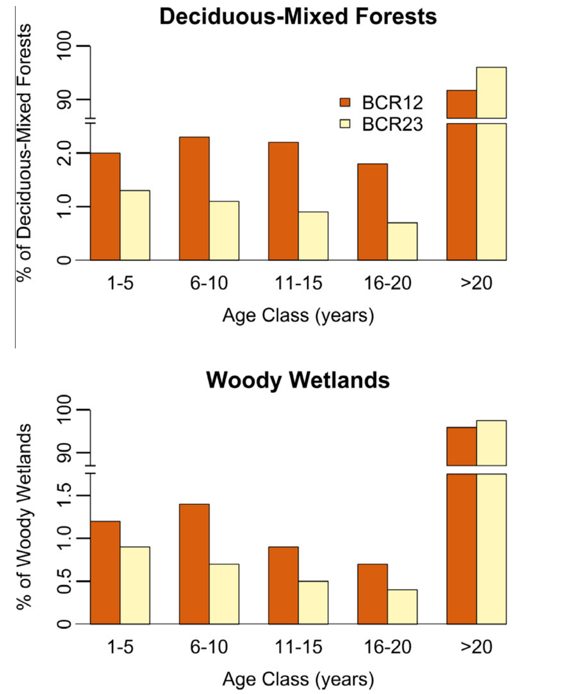

Fig. 2. Map-based percentages of deciduous-mixed and woody wetland forest age classes for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA. Percentages based on total area of deciduous-mixed forest or woody wetland age classes. Note that percentages of 5-year-age classes can be summed to determine the total percentage of a forest cover class $\leqslant$20 years of age.

age class for deciduous-mixed forests and woody wetlands was contained in patches $\geqslant$1 ha for BCRs 12 and 23, respectively (Fig. 4). Percentages in patches $\geqslant$1 ha for all age classes of both forest cover classes were smaller in BCR 23 than in BCR 12. A similar pattern was observed for core area (Fig. 5) as, almost without exception, all age classes for deciduous-mixed forests and woody wetlands possessed a greater percentage of core area in BCR 12 than 23. In both BCRs, core area constituted a small percentage of ESF age classes ($\leqslant$11.1%) and a relatively large percentage of the persisting age class ($\geqslant$18.4%) for both deciduous-mixed forests and woody wetlands.

3.4. Protection status

In BCR 12, greater than or equal to a half of each deciduous-mixed forest or woody wetland age class fell on lands with an unprotected or unknown protection status whereas more than three quarters of each age class occurred on unprotected or unknown protection status lands in BCR 23 (Fig. 6). Multiple-use lands held more than 22% of all age classes regardless of forest cover class and were a more common form of protection than restricted-use lands for all age classes in BCR 12. In contrast, within BCR 23, multiple-use lands did not always hold greater percentages

Table 1
Map-based areas (ha × 1000) and percentages (in parentheses) of land cover classes for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA.

Spatial extent	Open water	Developed	Barren	Shrub/scrub	Grassland/Herb.	Agriculture	Herb. wetlands	Deciduous-mixed	Evergreen	Woody wetlands
BCR 12	1334.5	861.3	55.5	116.0	264.7	1515.4	1139.1	8670.3	1745.0	5389.2
	(6.3)	(4.1)	(0.3)	(0.6)	(1.3)	(7.2)	(5.4)	(41.1)	(8.3)	(25.6)
BCR 23	719.9	2532.0	40.6	65.0	324.0	11142.0	658.5	4788.1	318.7	1402.1
	(3.3)	(11.5)	(0.2)	(0.3)	(1.5)	(50.7)	(3.0)	(21.8)	(1.5)	(6.4)

Table 2
Map-based percentages of shared edges among age classes of deciduous-mixed forests (left column) and woody wetlands (right) for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA.

Spatial extent	Age class	Deciduous-mixed forests						Woody wetlands					
		1–5 years	6–10 years	11–15 years	16–20 years	⩽20 years	>20 years	1–5 years	6–10 years	11–15 years	16–20 years	⩽20 years	>20 years
BCR 12	1–5 years	–	2.8	1.3	0.8	–	3.1	–	1.9	0.8	0.6	–	1.7
	6–10 years	3.3	–	3.2	1.4	–	3.3	2.2	–	2.6	0.8	–	1.8
	11–15 years	1.3	2.9	–	3.1	–	3.0	0.6	1.8	–	1.7	–	1.2
	16–20 years	0.7	1.0	2.5	–	–	2.5	0.4	0.4	1.3	–	–	0.9
	>20 years	60.7	56.4	56.0	59.3	61.8	–	53.4	49.7	46.3	50.4	52.1	–
BCR 23	1–5 years	–	1.9	1.2	0.9	–	1.8	–	1.5	0.6	0.7	–	0.9
	6–10 years	1.6	–	2.4	0.8	–	1.5	1.2	–	1.5	0.5	–	0.7
	11–15 years	0.8	1.9	–	1.7	–	1.2	0.4	1.1	–	1.1	–	0.5
	16–20 years	0.4	0.4	1.3	–	–	1.0	0.3	0.3	0.8	–	–	0.4
	>20 years	56.3	56.2	56.2	59.8	59.1	–	46.8	44.2	45.3	49.1	47.3	–

Table 3
Map-based percentages of shared edges between age classes and cover classes for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA. Percentages are reported for deciduous-mixed forest (left column) and woody wetland (right) age classes.

Spatial extent	Cover class	Deciduous-mixed forests						Woody wetlands					
		1-5 years	6-10 years	11–15 years	16–20 years	⩽20 years	>20 years	1-5 years	6-10 years	11–15 years	16–20 years	⩽20 years	>20 years
BCR 12	Deciduous-mixed forests	66.0	63.1	63.0	64.6	61.8	11.9	19.0	23.1	25.5	25.0	23.7	47.3
	Woody wetlands	11.8	14.0	14.4	14.7	14.7	35.4	56.6	53.8	51.0	53.5	52.1	5.6
	Herbaceous wetlands	4.0	3.9	4.4	3.9	4.4	6.2	12.9	11.3	12.9	11.9	12.7	17.9
	Agriculture	3.0	2.4	2.0	1.5	2.4	6.9	1.6	1.3	1.1	0.9	1.4	3.0
	Developed	5.8	6.0	6.5	5.4	6.3	13.9	3.3	3.5	3.6	3.0	3.5	7.3
BCR 23	Deciduous-mixed forests	59.1	60.4	61.1	63.2	59.1	5.5	16.1	16.6	17.6	15.9	17.0	44.7
	Woody wetlands	4.9	4.7	5.5	5.3	5.2	17.1	48.7	47.1	48.2	51.4	47.3	2.5
	Herbaceous wetlands	2.5	2.1	2.4	1.7	2.3	5.6	8.9	7.8	7.9	7.1	8.3	11.2
	Agriculture	20.6	17.4	14.8	15.3	18.2	45.0	15.6	15.8	14.7	14.2	15.6	22.3
	Developed	7.7	8.8	9.1	7.8	8.6	14.8	6.1	7.2	7.3	7.0	6.9	9.6

of deciduous-mixed forest or woody wetland age classes than restricted use-lands. This change in pattern was due to a large drop in percentages for multiple-use lands between BCRs 12 and 23 whereas the percentages for restricted-use lands remained comparatively stable across the two BCRs. Conservation easements include small percentages of deciduous-mixed forest or woody wetland age classes and did not contain more than 3.4% or 1.9% of any age class in BCR 12 or 23, respectively.

4. Discussion

Large-scale conservation plans, including the American Woodcock Conservation Plan (AWCP), have set ESF goals based on estimates and trends of total habitat area, but a lack of spatially explicit data has precluded consideration of patch and landscape characteristics by these plans. Using a novel, spatially explicit data set, we report areas and patch characteristics of ESF age classes for BCRs 12 and 23 within the YFI region. For deciduous-mixed forests, we found that ESF covered 3.4% and 0.9% of BCRs 12 and 23, respectively, whereas woody wetland ESF constituted 1.0% and 0.2% of these same BCRs. Within both BCRs and regardless of forest cover class, ESF often occurred in patches ⩾1 ha, possessed little core habitat, and mostly fell on lands possessing an unprotected or unknown protection status. ESF was arranged in smaller patches with less core area in BCR 23 compared to BCR 12. BCR 23 also possessed a greater percentage of ESF on lands with unprotected or unknown status. These results suggest that future management efforts should create large, ESF patches with high percentages of core area, especially in BCR 23. In either BCR, these management efforts likely will occur on multiple-use lands or lands of unknown/unprotected status owned by private individuals, companies, or public agencies with interest in or responsibility for silviculture or wildlife habitat management. Our spatially explicit data set and subsequent data sets will enable monitoring of progress toward achieving greater coverage by ESF in larger patches with more core area.

The defining advantage of our geospatial layer is the ability to apply patch and landscape filters to ESF assessments, and we found that estimates of suitable ESF are sometimes greatly reduced when such filters are applied. Consideration of patch size had the most dramatic effect in BCR 23 where, by number, approximately 80 percent of ESF patches were less than 1 ha in size, a minimum threshold patch size suggested by the work of Schlossberg and King (2007) and Shake et al. (2012); by area, a third of deciduous-mixed forest ESF and one half of woody wetland ESF in BCR 23 occurred in patches less than 1 ha in size. We note that not all ESF-dependent bird species will respond to patch size in the

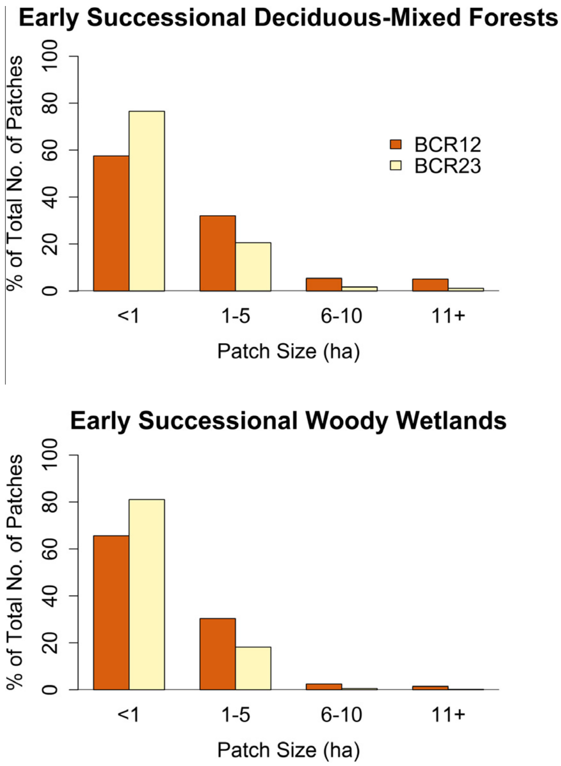

Fig. 3. Map-based percentage of the number of early successional (⩽20 years old) forest patches assigned to different size classes for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA. Percentage based on total number of early successional patches for deciduous-mixed forests and woody wetlands.

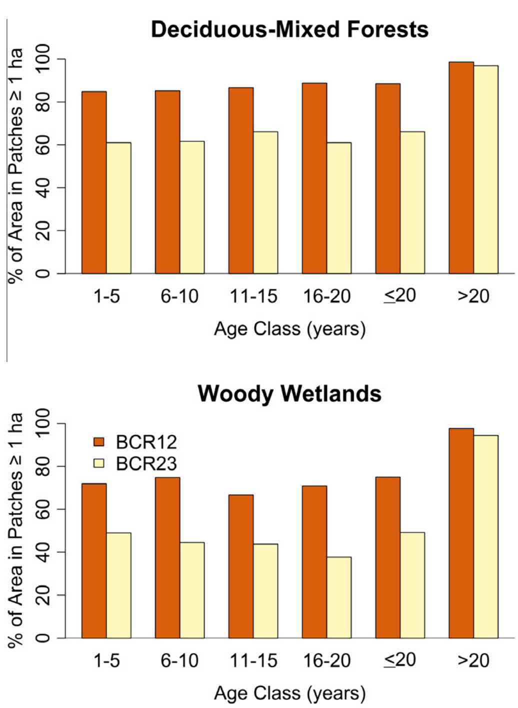

Fig. 4. Map-based percentage of area located in patches ⩾1 ha for each deciduous-mixed forest and woody wetland age classes for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA. Percentage based on total area of respective age class.

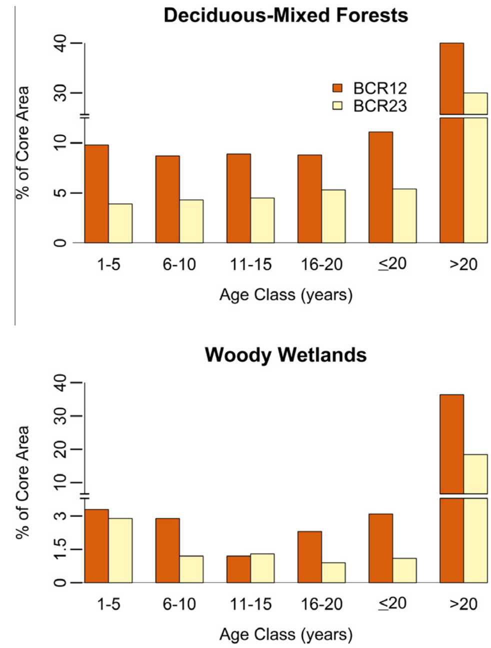

Fig. 5. Map-based percentage of core area for each deciduous-mixed forest and woody wetland age class for Bird Conservation Regions (BCR) 12 and 23 within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA. Core area was defined as greater than or equal to 60 m from an edge between the age class and another age or cover class. Percentage based on total area of respective age class.

same way, and some species may actually be more abundant in patches <1 ha in size (Kerpez, 1994). For species whose probability of occurrence or densities increase with patch size, such positive responses to increasing patch size may extend to 4 ha (Schlossberg and King, 2007), and user-defined patch size thresholds can be easily applied to our data set. Regionally, patch sizes could be increased through the application of even-aged silviculture or habitat management where appropriate (Annand and Thompson, 1997) and by joining future treatments to existing ESF patches (Gullion, 1984). Traditionally, this strategy has focused on publicly owned lands covering large areas and attributed with spatially explicit stand (patch) data detailing forest type (i.e., species composition), tree size (e.g., diameter at breast height), or tree density (e.g., trees per hectare). Regionally available, spatially explicit ESF data may now provide opportunities to extend these efforts across ownerships boundaries to include smaller parcels on privately owned lands.

Across both BCRs, a relatively small percentage of ESF for deciduous-mixed forests and woody wetlands occurred in core areas, i.e., ⩾60 m from a patch edge. Past researchers have characterized ESF-dependent species as 'edge species' (e.g., Freemark and Collins, 1992), but recent researchers have suggested that associations with edges may reflect ESF availability not a preference for edges per se (Roth and Lutz, 2004; Schlossberg and King, 2008). Indeed, Schlossberg and King (2008) recently reported that abundances for a suite of shrubland birds were greater in habitat interiors (>60 m from a mature forest edge) than near edges (<30 m from mature forest). Microclimate and environmental conditions change as one moves from the edge of a clearcut toward its center (e.g., increased warmth and dryness, Godefroid et al., 2006), and these microclimate changes could affect resources important to ESF-dependent species. However, Rodewald and Vitz (2005) found no changes in vegetation, fruit abundance, or arthropod biomass within clearcuts as distance to mature forest edge increased. Rather than active edge avoidance, King et al. (1997) suggested

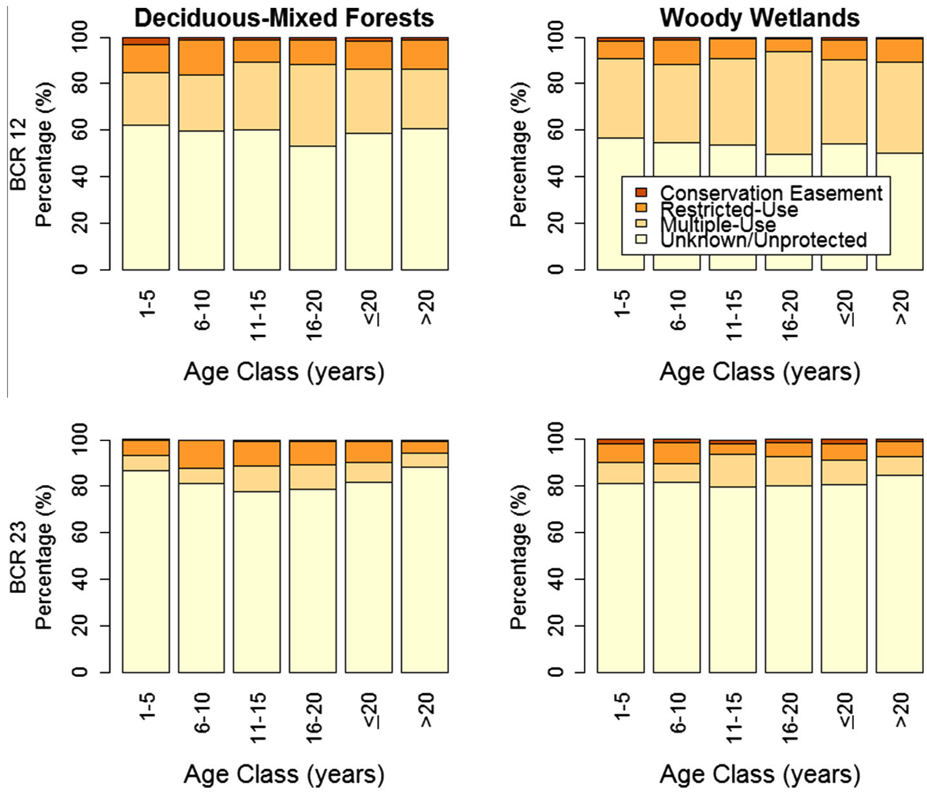

Fig. 6. Map-based percentage of deciduous-mixed (left column) and woody wetland (right) age classes located on lands of different protection status. Results are presented for Bird Conservation Regions 12 (top row) and 23 (bottom) within the Upper Great Lakes Young Forest Initiative region of Michigan, Wisconsin, and Minnesota, USA.

that apparent edge sensitivity may be due to birds being unable to fit enough circular territories along patch edges to equal territory densities found in forest interiors. While the above studies address edges between forest patches of differing age, we found that ESF commonly shared edges with nonforest cover classes, including developed and agricultural lands, especially in BCR 23. The scale of and underlying mechanisms driving edge effects likely differ depending on the type of edge (Ries et al., 2004), and this represents an important area for future ESF research. Edge effects will be greatest for small and irregularly shaped patches, and consequently, ESF management recommendations regarding edge avoidance are broadly the same as those made for area sensitivity above, i.e., enlarge patches and cluster forest treatments as well as maximize percentages of core area for patches.

The need to address area sensitivity and edge avoidance should be balanced by the need to juxtapose different forest and age classes. Many wildlife species are labeled, e.g., “deciduous mature forest” or “young forest” species, but there is clear evidence that focal species depend on multiple forest and age classes to complete their annual cycles. For example, Vitz and Rodewald (2006) documented use of regenerating clearcuts by fledglings of mature forest bird species, and Streby et al. (2015) document the opposite movement pattern for Golden-winged Warblers moving from ESF breeding and nesting habitat into nearby mature forest patches post-fledging. For both BCRs, most ESF 5-year age classes fall within or adjacent to persisting cover of the same forest class, e.g., woody wetland ESF tends to share edges with persisting woody wetlands. Adjacencies between 5-year age classes were much less common. For each age class of deciduous-mixed forest, shared edges with woody wetlands were relatively common and vice versa. Effective management for forest and age class juxtaposition will require continued efforts to understand the habitat needs of species throughout their life cycles. In addition, planning forest age class juxtaposition requires an understanding of species’ ecological neighborhoods, or the area over which an organism is active for a given period of time (Addicott et al., 1987). For example, to support an autumnal population of 500 individuals, best management practices for woodcock have identified the need for a management unit of 200–400 ha and composed of 80% feeding, nesting, and brood-rearing habitat and 20% roosting and courtship habitat (Wildlife Management Institute, 2009). Simultaneously meeting the needs of species with diverse habitat needs will require a balanced management approach at a regional scale.

Landownership and associated management patterns are recognized as an important challenge to ESF creation and management (Brooks and Birch, 1986; Brooks, 2003). We found that the majority of ESF occurred on lands with an unprotected or unknown protection status. This is not surprising, given that the majority of ESF is associated with timber harvest activities within the YFI region. Within the unprotected class, population growth and human migration from cities to suburban and rural areas can drive habitat loss and the breaking of large private forest ownerships into smaller ones, a process referred to as parcelization (or parcelation). We expect parcelization and the control of parcels by owners with diverse interests (not always aligned with silviculture or wildlife habitat management) will increase the difficulty of implementing meaningful ESF management in the future. For owners interested in forest management, small and dispersed parcels might make harvest uneconomical for professional loggers (Kittredge et al., 1996). Multiple-use lands harbored 22.7% or more of each ESF 5-year age class in BCR 12 and 6.4% or more in BCR 23. On these lands, timber harvest can be used to maintain or create ESF, but ESF management will be balanced by potentially conflicting objectives, e.g., providing recreational opportunities. Restricted-use lands, such as designated wilderness areas, held greater than 5% and 4% of each ESF 5-year-age class in BCRs 12 and 23, respectively. By definition, restricted-use lands are not open to active ESF management, so we assume that ESF originates mostly from natural causes on these lands. Currently, conservation easements do not play a large role in the protection of ESF within the region, which is not surprising given that easements contribute 2% or less of overall protection for the majority of natural vegetation types across the United States (Foster et al., 2014). In summary, the greatest opportunities for ESF management likely exist on multiple-use lands or lands of unknown/unprotected status owned by private individuals, companies, or public agencies with interest in or responsibility for silviculture or wildlife habitat management.

There are at least two ways to evaluate the amount of ESF present within the YFI region (Askins, 2001). Here, we are speaking of the total amount of ESF unfiltered by patch and landscape metric qualifiers. One standard is the amount of ESF present at a historical baseline as it is assumed that species evolved and are adapted to historical conditions. When compared to previously published estimates, our results suggest that ESF abundances for deciduous-mixed forests and woody wetlands have fallen from historical levels. Lorimer (2001) reported that young forest <15 years old and barren areas covered 7.5–13.2% of the Laurentian Mixed Forest (Bailey and Cushwa, 1981) in northern Michigan and Wisconsin prior to European settlement. The Laurentian Mixed Forest approximates the boundaries of BCR 12 within the YFI region, and we found that ESF of deciduous-mixed forests and woody wetlands combined to cover 4.5% of BCR 12. Lorimer (2001) also stated that prairies and savannas covered at least half of the central hardwoods in southern Minnesota and Wisconsin, an area falling within BCR 23 (Knutson et al., 2001; Fralish, 2003). Our assessments indicated that cover by ESF of deciduous-mixed forests and woody wetlands summed to 1.1% of BCR 23. Definitive conclusions based on comparisons of published estimates and our own estimates are difficult to reach because of differences in spatial units and habitat definitions and because there are inaccuracies in historical and contemporary data sets. Such difficulties illustrate challenges associated with managing to achieve historical baselines. Other challenges include the uncertainty in selecting an appropriate baseline (King and Schlossberg, 2014) and constraints (e.g., suppression of natural disturbances) imposed by modern landscapes that make historical conditions unattainable.

An alternative standard is defined by the amount of ESF needed to secure species populations and associated ecosystem services (Askins, 2001; Kelley et al., 2008). AWCP has established ESF goals to restore woodcock populations of singing males to densities observed during the 1970s, and this restoration is to ensure "adequate opportunity for the utilization of the woodcock resource" (Kelley et al., 2008). Based on AWCP, Cooper (2008) set ESF goals of maintaining 4.7 million ha currently available in the YFI region and of adding 1.5 million hectares of potentially suitable habitat within 20 years. Cooper (2008) defined and assessed ESF using 2005 FIA area estimates of small-diameter stands. FIA-based estimates in Kelley et al. (2008) and Cooper (2008) are based on timberland – a subset of forest land that is productive and not reserved (Woudenberg et al., 2010); timberland encompasses 90%, 95%, and 97% of Minnesota, Michigan, and Wisconsin forest land, respectively. For the region, FIA estimates (2010–2014) put the area of small-diameter stands at 4.97 million ha of timberland (Miles, 2015), so it appears the goal of maintaining ESF has been met – if ESF is assumed to be represented by small-diameter forest without applying other filters.

Different ESF definitions account for a majority of the difference observed between our ESF map-based estimate of young forest and the FIA-based estimate of small diameter stand-size class forest in Cooper (2008). We report 1.2 million ha of deciduous-mixed forest and woody wetland ESF available across the YFI region (BCRs 12 and 23 combined), less than a third of the total reported by Cooper (2008). We identified ESF as forestland ⩽20 years after a canopy-clearing disturbance as of 2009 whereas Cooper (2008) defined ESF using FIA's small-diameter forest estimates for 2005. Within the Upper Great Lakes states, FIA area estimates for stands ⩽20 years old can be much less than estimates for small-diameter stands on forest land. For example, Perry et al. (2012) reported that 80% of Wisconsin 0–20 year-old forest was in small diameter size class, but only 47% of small diameter size class was in 0–20 year-old forest during 2005–2009. Additionally, FIA data indicate little change in the area of small-diameter stands on timberland during the past decade (Miles, 2015), so temporal trends do not appear to account for the observed difference between estimates. The disagreement between estimates demonstrates that forest age and structure (e.g., stand diameter size) are imperfectly correlated but may serve as complementary sources (Perry et al., 2012). Consequently, successful ESF management at multiple scales will require diverse assessment and monitoring data sets and approaches, including use of FIA data and geospatial layers.

The geospatial layer used for our assessments should be viewed as a model of ESF conditions across the YFI region, and responsible use of this model requires careful consideration of its underlying assumptions and limitations. As detailed above, the geospatial layer is based on canopy-removing disturbances detected through remote sensing, and our ESF estimates will, to varying degrees, disagree with estimates using different definitions or techniques. In a comparison with FIA plot-based stand age data, Garner et al. (2016) found that the RDS modified for use in this study tended to omit ESF. Omissions could simply be due to layer classification errors, errors within the FIA data, or definitional differences between map year of disturbance and FIA stand age. Thomas et al. (2011) found that validation with FIA plot-based data resulted in lower accuracy for remotely sensed forest disturbance products than comparisons with human interpretation of Landsat imagery and higher resolution imagery. As a result, we believe the results of Garner et al. (2016) are conservative, but we currently lack an alternative to FIA plot-based data for regional validation. Future research should evaluate the potential influence of ESF omission errors on wildlife habitat metrics (Fleming et al., 2004).

New and emerging spatial techniques and products, such as the ESF map used in this study, are creating novel opportunities for wildlife managers to assess patch and landscape aspects of ESF at a regional scales. For the YFI region, our assessment indicates that considering these spatial aspects can greatly alter the perceived quantity of suitable ESF on the landscape. We anticipate these spatial products and analyses complementing traditional data sources, such as FIA, to provide context for revising habitat management plans and to enable monitoring of management progress toward ESF habitat goals.

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