# EFFECTS OF SILVICULTURAL PRACTICES ON BIRD COMMUNITIES IN DECIDUOUS FORESTS OF EASTERN AND CENTRAL NORTH AMERICA

*A Literature Review with Recommendations for Management*

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October 2008

## Introduction

Researchers have reported significant population declines in forest bird species throughout central and eastern North America (Robbins et al. 1993, Herkert 1995, Thompson 1996, Rich et al. 2005, La Sorte et al. 2007). While some researchers have noted declines in forest species that require large areas of mature, minimally disturbed, contiguous forest cover (Robbins et al. 1989, Robinson et al. 1995, Hoover et al. 1995, Thompson 1996, Rosenberg et al. 1999), others have simultaneously reported concern for disturbance-dependent species that require early-successional habitats such as young, regenerating forest and scrub-shrub communities (Askins 2001, Dessecker and McAuley 2001, Hunter et al. 2001, Dettmers 2003, Murphy 2003, American Bird Conservancy 2006). Herkert (1995) reported Midwest bird abundance trends since 1966 and found significant declines in 50% of early-successional species and 36.2% of woodland species reviewed. Conservation of these species requires a thorough understanding of their habitat requirements and how land management activities affect the structural and spatial characteristics of these habitats (Robbins et al. 1989). Given the extensive assemblage of avifauna inhabiting the forests of central and eastern North America – each with different specific habitat requirements from the next – managing for the needs of all species can be challenging. Balancing the needs of early- and late-successional forest species at any given location is difficult as the management techniques used to create and maintain these communities are often viewed as mutually exclusive of one another – i.e., managing a forest for late-successional species by restricting timber harvesting will limit its suitability for many disturbance-dependent species. As a result, many researchers suggest implementing a wide variety of land management strategies across forested landscapes to better address the needs of all species represented.

Intact, diverse, and healthy bird communities are essential to ecologically sustainable forests and conservation of all bird species should be a priority in forest management planning. Managers need a better understanding of how forest management activities affect late-successional species requiring elements of mature forests and disturbance-dependent species that require early-successional forest communities. To this end, the purpose of this paper is to review current research on the effects of silvicultural practices on eastern and central North American forest birds and to suggest management strategies for promoting avian species diversity on managed forests.

## The Role of Sustainable Forest Management

In recent decades public forest managers have adopted a broader approach to forest management that includes consideration for ecological processes and biological diversity on managed landscapes. Philosophies such as ecosystem management and sustainable forestry came about in response to the "deepening biodiversity crisis" (Grumbine 1994) observed throughout the second-half of the 20th century and have been adopted by natural resource agencies worldwide (Brown and Marshall 1996, Thomas 1996, Noble and Dirzo 1997). Central to both philosophies is the recognition that land managers consider native flora and fauna, their habitats, and natural ecological processes when planning and implementing management activities (Kessler et al. 1992, Freemark et al. 1993, Slocombe 1993, Carey and Curtis 1996, Brunner and Clark 1997, Czech and Krausman 1997, Grumbine 1997). Additionally, this broader approach requires land mangers to consider issues related to landscape ecology and how their local management activities may have far-reaching effects on regional populations of wide-ranging or migratory species, such as birds, bats, and large carnivores (Freemark et al. 1993, Boutin and Hebert 2002).

In Indiana, the legislation that provides the foundation for the management of state forests (IC 14-23-4-1) states:

*"It is the public policy of Indiana to protect and conserve the timber, water resources, wildlife, and topsoil in the forests owned and operated by the division of forestry for the equal enjoyment and guaranteed use of future generations. However, by the employment of good husbandry, timber that has a substantial commercial value may be removed in a manner that benefits the growth of saplings and other trees by thinnings, improvement cuttings, and harvest processes and at the same time provides a source of revenue to the state and counties and provides local markets with a further source of building material."*

Additionally, it is the mission of the Division of Forestry's Property Section to "manage, protect and conserve the timber, water, wildlife, soil and related forest resources for the use and enjoyment of present and future generations, and to demonstrate proper forest management to Indiana landowners." Such management efforts are inherently comprehensive, requiring an integrated approach based on the philosophies of sustainable forestry. In recognition for its commitment to sustainable forest management, the Indiana Division of Forestry has received "green" certification from independent auditing organizations. State forest properties and programs have met the rigorous standards and criteria required by the *Sustainable Forest Initiative* and *Forest Stewardship Council*, ensuring that forest management activities are environmentally sound and socially acceptable.

## Forest Management Practices and Effects on Bird Communities

Like natural disturbance events, such as windstorms, wildfires, and seasonal flooding, timber harvests affect the forest breeding bird community to different extents, depending on the type of harvesting, the surrounding landscape type, and the bird species present (Brawn et al. 2001). Additionally, as vegetation in young forest stands changes over time, transformations in forest bird communities are anticipated in both managed (Campbell et al. 2007) and unmanaged forests (Brawn et al. 2001, Holmes and Sherry 2001). Since bird communities are dynamic and change in relation to natural forest succession – even in the absence of forest management activities – long-term effects of management are often difficult to separate from natural processes. Therefore, meaningful evaluations of harvesting effects need to consider both spatial and temporal changes in habitat conditions and how these compare to historic and present-day disturbance events that shape the forest community.

In the face of such complexity, making value-based generalizations about timber harvesting effects can be ineffectual. For instance, simply referring to a clearcut as universally 'bad' ignores its benefit to many disturbance-dependent species that only nest within early-successional forest habitat. Even the temptation to label recent clearcuts 'bad' specifically for late-successional species that require mature forest habitat for nesting, ignores the important benefit such forest openings offer these species for foraging during the post-breeding and migratory seasons (Kilgo et al. 1999, Pagen et al. 2000, Keller et al. 2003, Marshall et al. 2003, Vitz and Rodewald 2006). Further complicating the value of a clearcut is the reported effect large forest openings may have on nest predation and brood parasitism, which appears to largely depend on the surrounding characteristics of the landscape and local assemblage of nest predators (Donovan et al. 1997, Rodewald and Yahner 2001, Thompson et al. 2002, Thompson and Burhans 2003). Clearly, value-based generalizations are of limited value when considering the complexity inherent in and among forest communities, managed or not.

Managing forests and bird habitat to the benefit of all species and across all community types is challenging given the complexity of factors affecting these various populations. To help land managers with this task, this paper will present an extensive and comprehensive review of recent research that examined how bird communities, species, and habitats were affected by various silvicultural methods. Effects will be discussed as they pertain to the two general categories of regeneration systems – even-age and uneven-age – as well as two commonly prescribed practices, intermediate cutting (e.g., thinning) and prescribed burning.

*Silvicultural Regeneration Systems – Uneven-age Management*

Silvicultural systems involve the predictable regeneration of forest trees, typically through the choice of one of many harvesting techniques. When forest managers consider harvesting and regeneration activities, they typically do it over a relatively small unit of the forest, such as a *stand* of trees. Stands are portions of forest that usually have trees sharing common characteristics, such as the same dominant species, age classes, or a common topographic feature, such as a ridge slope. Uneven-age silvicultural systems are harvest techniques that eventually result in a stand made up of three or more age classes. Entries are made into the stand periodically – perhaps every 10-20 years – to remove dispersed, individual trees (single-tree selection) and/or small groups of trees (group selection) throughout the stand. The resulting openings support regenerating trees and associated vegetation, such as herbs, grasses, and shrubs. Foresters guide the composition of regenerating species by knowing each individual tree species' light requirements and varying the opening size to suit some species while discouraging others. For instance, some species such as sugar maple can grow relatively quickly in partial light and some shade, while white oak does not grow as fast in such environments but can out-compete sugar maple in more open areas with plentiful light. By knowing a species' growth requirements, such as its shade tolerance, foresters can manage for either shade-tolerant species (e.g., sugar maple) with small canopy openings or more shade-intolerant species (e.g., yellow poplar and white oak) that benefit from more available light and larger openings. One important feature common among all uneven-age systems is that at any given time in a stand there is a relatively large proportion of older, mature trees available. The effects of uneven-age selection methods often resemble those caused by natural disturbance events such as light- and moderate-intensity ice and wind storms (Greenberg and Lanham 2001, Faccio 2003).

Just as harvesting intensity and the resulting opening size affects tree regeneration, other forest inhabitants can be affected by the choice of opening size and the tree species that management favors (Chadwick et al. 1986, Lorimer 1994). At the stand level, researchers have found that, in general, uneven-age systems retain or attract bird species that require habitat conditions found in mature forests (Hamel et al. 2006, Campbell et al. 2007, Holmes and Pitt 2007); however, at the same time, these systems may not offer suitable habitat for birds that require large areas of young, regenerating, early-successional forest (Costello et al. 2000, DeGraaf and Yamasaki 2003). When single-tree selection systems are used alone or in conjunction with stand-wide group selection prescriptions, researchers found that many bird species that typically nest in mature forest were as abundant in harvested stands than in nearby, unharvested stands or in the same stand prior to harvesting (Robinson and Robinson 1999, Doyon et al. 2005). This was generally true, researchers believed, because a major characteristic of mature forest – intact canopy structure - was largely retained around the small single-tree gaps, even though a portion of the trees had been harvested from the stand. Researchers note that some habitat conditions for late-successional bird species actually improved in stands harvested using single-tree selection techniques, when compared to unharvested stands. Doyon et al. (2005) found that bird species typically associated with late-successional northern hardwood forests, such as the black-throated blue warbler, benefited from the increase in shrubs and understory trees that resulted from improved light levels in stands harvested using single-tree selection. Robinson and Robinson (1999) found that the small openings created by single-tree selection favored hooded warblers, a species of mature forests that uses small, shrubby gap areas.

Most research examining uneven-age techniques involves group selection, which is often done in conjunction with single-tree selection (Law and Lorimer 1989). As with single-tree selection alone, the addition of small group selection openings in a stand often retains much of the mature forest bird assemblage that existed before the stand was harvested or simultaneously exists in nearby uncut stands (Annand and Thompson 1997, Germaine et al. 1997, Robinson and Robinson 1999, Costello et al. 2000, Gram et al. 2003, Campbell et al. 2007, Holmes et al. 2007). Though researchers have found some bird species that typically nest within forest interiors decreased within recent group openings, studies also report the abundance and, if studied, nesting success of these same species outside the opening area were unaffected by the harvest (Germaine et al. 1997, Costello et al. 2000, Robinson and Robinson 2001, Moorman et al. 2002, Gram et al. 2003, Campbell et al. 2007). Researchers also report songbird species diversity in stands harvested using group selection either increased or was unaffected by harvesting activities (Annand and Thompson 1997, Robinson and Robinson 1999, Costello et al. 2000, Campbell et al. 2007). Increased avian species diversity is most often attributed to the retention of forest interior species and an increase in species that require interior-edge, forest gaps, and early-successional habitats, which are all created by group selection harvesting (Lorimer 1994, Lent and Capen 1995, Thompson et al. 1995, Robinson and Robinson 1999, Greenberg and Lanham 2001).

While the abundance and presence of species are important indicators of habitat use, estimates of nest success are often viewed as the most appropriate indicator of habitat quality as it pertains to productivity (Van Horne 1983). Though studies of nest success and survival are less common than those of abundance, the few studies that have been done suggest group selection harvests have little overall effect on songbird productivity across managed stands (Robinson and Robinson 2001, Moorman et al. 2002, Gram et al. 2003, King and DeGraaf 2004). One concern with forest openings is that they may provide suitable habitat for nest predators (e.g., raccoons, blue jays, crows) and brood parasites (e.g., brown-headed cowbird) that prey upon forest bird nests near opening edges (Robinson et al. 1995, Thompson et al. 1996, Donovan et al. 1997). However, most authors found nest predation and parasitism to be generally low in association with selection harvesting (Annand and Thompson 1997, Germaine et al. 1997, King et al. 2001, Moorman et al. 2002, Gram et al. 2003). This is particularly true in heavily forested landscapes where nest predator and brood parasite populations are relatively low (Annand and Thompson 1997, Donovan et al. 1997, Rodewald and Yahner 2001, Moorman et al. 2002).

Few studies have examined the long-term effects of selection harvesting, though those that have found conditions continue to remain beneficial for late-successional species over time, while habitat for early-successional species wanes unless new openings are created within 15-20 years (DeGraaf and Yamasaki 2003, Campbell et al. 2007). Campbell et al. (2007) studied 20 years of bird response to group selection harvests and found that mature forest species were successfully retained throughout the entire study period but early-successional species were only temporarily benefited by the harvests. Their conclusion was that natural forest succession dynamics eventually made regeneration openings unsuitable for early-successional species and that forest-wide retention of this species group would require additional openings to be created periodically (Campbell et al. 2007).

Selection harvesting has been found to be a useful method for land managers seeking to increase songbird species diversity on mature forest tracts as it retains mature forest species, while also providing habitat for some species that require forest gaps and early-successional forest patches. Researchers have reported that habitat suitability for early- and late-successional species largely depends on the size of openings and the availability of suitable forest structure for each guild (Lent and Capen 1995, DeGraaf et al. 1998, Kilgo et al. 1999, Costello et al. 2000, DeGraaf and Yamasaki 2003, King and DeGraaf 2004, Bulluck and Buehler 2006, Askins et al. 2007, Holmes and Pitt 2007). Small regeneration openings have been shown to benefit mature forest species that also use early-successional shrub habitat found in small forest gaps, such as hooded and worm-eating warblers (Annand and Thompson 1997, Gram et al. 2003, Campbell et al. 2007). Larger group selection openings provide habitat for more area-dependent early-successional species such as chestnut-sided warbler and indigo bunting (King et al. 2001, Gram et al. 2003, King and DeGraaf 2004, Alterman et al. 2005, Askins et al. 2007). However, group selection openings are rarely large enough to provide suitable habitat for the complete suite of early-successional forest bird species, many of which appear to prefer larger openings (Brito-Aguilar 2005, Rodewald and Vitz 2005). To support viable, sustainable populations of these species and ultimately ensure high species diversity across forested landscapes, authors suggest using a variety of harvesting methods, including those that produce larger areas of regenerating forest (Lent and Capen 1995, Costello et al. 2000, DeGraaf and Yamasaki 2003, Gram et al. 2003, Alterman et al. 2005, Doyon et al. 2005, Rodewald and Vitz 2005, Askins et al. 2007, Campbell et al. 2007, McDermott 2007).

*Silvicultural Systems – Even-age Management*

Even-age silvicultural systems generally result in one or two age-classes across forest stands and include clearcut, shelterwood, seed tree, and two-age harvests. Openings resulting from even-age harvests are typically larger than individual group selection openings, as the entire stand is affected, rather than only a portion of it. These larger openings benefit shade-intolerant tree species that compete best when light is plentiful. Harvests are generally limited to one or possibly two entries in even-age systems, while in selection systems harvesting within the stand often typically occurs every 10-20 years. Due to these characteristics, even-age systems tend to model the effects of natural disturbance regimes such as large windstorms and fires that infrequently affect relatively large areas (Thompson and DeGraaf 2001).

Even-age regeneration systems differ primarily in the quantity of trees that are retained from the original stand. Under the clearcut method, all trees are harvested except for snags and other designated “wildlife trees” that are retained to serve as wildlife habitat within the regenerating stand (DeGraaf and Shigo 1985, Tubbs et al. 1987, Franklin et al. 2007). With shelterwood and seed tree methods a portion of the stand’s mature trees are retained to provide shelter and seed for the developing regeneration. Typically, residual mature trees are removed once regeneration objectives have been met, although in some circumstances they are retained to meet other objectives related to wildlife habitat or aesthetic quality. Choosing to retain residual structure within even-age stands will result in two age classes – the new regeneration and older residual trees.

Clearcutting is one of the most common – and controversial – even-age methods used, and as a result, much of the literature focuses on its role in bird management. In general, at the stand-level, recent clearcuts have been found to provide suitable nesting and foraging habitat for early-successional species while temporarily displacing some late-successional species that typically nest in mature forest (Annand and Thompson 1997, Baker and Lacki 1997, Costello et al. 2000, Duguay et al. 2001, Gram et al. 2003, Keller et al. 2003, Harrison and Kilgo 2004, Bulluck and Buehler 2006, Hanowski et al. 2006, Wallendorf et al. 2007). The positive response of early-successional species to regenerating even-age stands is associated with the vigorous growth of young trees, shrubs, vines, and herbaceous plants that create unique nesting and foraging opportunities, particularly in otherwise heavily forested landscapes (Annand and Thompson 1997, Keller et al. 2003, Doyon et al. 2005, Conner et al. 2006, Fink et al. 2006).

Though recent clearcuts may not offer suitable nesting habitat for many late-successional specialists, many authors report high use of clearcuts by species typically associated with mature forests (Pagen et al. 2000, Keller et al. 2003, Marshall et al. 2003, King et al. 2005, Vitz and Rodewald 2006, McDermott 2007). Vitz and Rodewald (2006) found a wide range of late-successional forest birds using clearcuts after the nesting season, with late-successional individuals accounting for over one-third of mist net captures. In this study, ovenbirds – a species typically associated with large areas of mature forest – were among the most frequently encountered species in recent clearcuts (Vitz and Rodewald 2006). Use of clearcuts by late-successional species is associated with the favorable foraging habitat that regeneration openings offer during the post-breeding and migratory seasons. Such openings typically support high populations of insects and fruit-bearing shrubs and vines which are important to the seasonal dietary requirements of many birds (Keller et al. 2003, McDermott 2007). Additionally, the dense vegetative cover provided by young regeneration openings may offer increased protection from predators. Due to the unique foraging and nesting opportunities even-age harvests bring to forested areas, many authors report higher songbird species diversity at these sites than in the mature forest areas they also studied (Annand and Thompson 1997, Baker and Lacki 1997, Costello et al. 2000).

Some research suggests the size of the even-age regeneration opening does not affect the species composition of the songbird community; however, other studies suggest some disturbance-dependent species are area-sensitive and select nesting habitat based on the amount of early-successional forest habitat available (Lent and Capen 1995, Costello et al. 2000, Gram et al. 2003, Alterman et al. 2005, Brito-Aguilar 2005, Rodewald and Vitz 2005, Askins et al. 2007). Brito-Aguilar (2005) found that clearcuts between 7 and 25 acres supported the greatest abundance of early-successional birds, while at the same time not affecting the mature forest bird community of the surrounding landscape. Rodewald and Vitz (2005) found 7 of 8 early-successional forest species were area-sensitive in southern Ohio, showing a positive correlation between abundance and the area of recently clearcut forest. In this study, twice as many birds were captured within clearcuts far (80 m) from mature forest edges compared to captures near (20 m) edges (Rodewald and Vitz 2005). The authors suggest that some early-successional forest birds tend to avoid the edges of clearcuts in favor of opening interiors and may prefer larger openings that optimize the ratio of young forest area to edge (Rodewald and Vitz 2005).

Shelterwood harvesting typically retains some sound mature canopy trees for several years after the initial regeneration cut. While the resulting early-successional bird community generally resembles that of clearcuts, some researchers have found that retaining mature canopy trees within shelterwood stands for even a brief period of time provides benefits for mature forest species (Annand and Thompson 1997, Augenfeld et al. 2008). Such benefits were also found for two-age stands where some mature structure is retained throughout the stand rotation (Rodewald and Yahner 2000).

Harrison and Kilgo (2004) found greater species diversity and bird densities in two-age harvests than clearcuts. In many cases researchers found stand use by late-successional species to remain high throughout the various development phases of such stands, though benefits for early-successional species diminished as the stand matured (McDermott 2007). Keller et al. (2003) examined the effects of even-age harvests on bird communities and habitat in relation to stand age, noting that the benefits of early-successional habitat on disturbance-dependent species is highly transitory due to natural forest succession. As the harvested forest stand develops, early-successional conditions give way to mature forest resulting in an associated re-organization in bird species composition, generally similar to that which occurs in the years following natural disturbance events of similar scale (Brawn et al. 2001, Holmes and Sherry 2001).

As with uneven-age silviculture, the effects of even-age harvesting on nest success has been less studied than effects on abundance; however, when studied, much of the focus has been on whether the edges of even-age regeneration openings have negative impacts on nesting success (i.e. "edge-effects"; Thompson et al. 1996). Duguay et al. (2001) compared nest success between clearcuts, two-age cuts, and mature forest in West Virginia and found no differences among nearly all species studied. Furthermore, they found the success of nests located in the uncut periphery around harvests was unaffected by the distance of the nest to the edge of clearcuts or two-age harvests. This was true, even for wood thrush, a species believed to be sensitive to edge-effects (Duguay et al. 2001). Hanski et al. (1996) studied the nest success of many species in Minnesota and reported no evidence of edge-effects around even-age harvests. In Missouri, Gram et al. (2003) studied nest success before and after even-age harvesting and found no differences among all five species studied that nested in mature forest. In South Carolina, Moorman et al. (2002) found no evidence for edge-effects around clearcuts in their study of hooded warbler nest survival and productivity. Conversely, Manolis et al. (2002), reported declines in ovenbird and hermit thrush nest success in relation to distance from clearcut edges. Flaspohler et al. (2001), too, found lower nest success for ovenbirds and hermit thrushes near clearcut edges, though they suggest edge-effects may be species specific since they saw no such effects in the other species they studied. King et al. (1996) also found distance to edge affected the survival of ovenbird nests in their study; however, the overall proportion of pairs fledging young and the numbers of young fledged per pair were unaffected by distance from edge.

Most studies of nest failure in relation to even-age harvests found predation was the primary source of loss (e.g., Duguay et al. 2001, Dellinger et al. 2007, Gram et al. 2003, Hanski et al. 1996, Manolis et al. 2002). Additionally, many studies – particularly those conducted in agriculturally dominated landscapes of the Midwest – have reported high incidence of brood parasitism affecting interior- and edge-nesting forest songbirds, typically from brown-headed cowbird (Robinson et al. 1995, Robinson 1996, Donovan et al. 1997, Thompson et al. 2002). Highest brood parasitism and predation rates are evident in isolated woodlots and forests highly fragmented by development and agriculture (Robinson et al. 1995, Robinson 1996, Donovan et al. 1997, Thompson et al. 2002). Though widespread throughout much of the Midwest and portions of eastern North America, the severity of the problem does not appear to be universal to all forests in this region, with extensively forested areas of the Missouri Ozarks, northern Wisconsin, and south-central Indiana showing low levels of nest predation and parasitism (Robinson et al. 1995, Robinson 1996). In south-central Indiana, Winslow (2003) found that cowbird brood parasitism rates there were lower than what had been reported in other Midwestern studies, positing this difference was due to the heavily forested conditions in which he worked. Rodewald (2002), citing a review by Andren (1995), points out most (88%) studies of edge-related nest predation in forested landscapes found no significant edge-effects, unlike studies conducted in forests heavily fragmented by agriculture or development.

Many researchers have concluded incidence of edge-effects and vulnerability to nest predation and brood parasitism are best interpreted at the landscape level using variables such as percent forest cover. Robinson et al. (1995) reported brood parasitism and nest predation rates for several forest species were correlated with the proportion of forest cover across landscapes having a 10-km radius. Donovan et al. (1997) found that percent forest cover predicted the incidence of predation and abundance of cowbirds at both interior and edge habitats within Midwestern landscapes of 864 $km^2$. In landscapes where forest cover was severely or moderately fragmented (<15% and 45-55% forest cover, respectively), nest predation rates were higher along forest-field edges than forest interiors; however, such edge-effects were not detected in unfragmented landscapes (>90% forest cover) (Donovan et al. 1997). Additionally, Donovan et al. (1997) were unable to detect any edge-effects relative to cowbird parasitism in any landscape type; however, cowbird abundance was significantly higher in highly fragmented landscapes than in moderately and unfragmented landscapes, but abundance in moderately and unfragmented landscapes did not differ. Porneluzi and Faaborg (1999) compared ovenbird productivity and survival between forested landscapes (10 km radius) that were fragmented by pasture and row crop (33-42% forest cover) and unfragmented (>90% forest cover). They concluded that ovenbird populations in fragmented forests were not self-sustaining due to high predation and brood parasitism rates, while those in unfragmented forests were self-sustaining and may serve as source populations for regional fragmented forests (Porneluzi and Faaborg 1999.).

Rosenberg et al. (1999) state "[i]t is important to distinguish between forest that is fragmented by agricultural or urban development and a forested landscape composed of a mosaic of mature and regenerating stands that result from timber harvesting", concluding that the fragmentation effects of agriculture and development are typically more damaging to forest bird populations. Rodewald and Yahner (2001) compared nest success in forested sites disturbed by either agricultural openings (primarily row crops and pastures) or even-age regeneration openings (clearcuts) in central Pennsylvania. Overall, nest survival among all species studied was significantly lower in forested areas disturbed by agriculture compared to even-age forest management. Additionally, cowbirds and American crows, an important nest predator, were significantly more abundant in forested landscapes disturbed by agriculture than by even-age regeneration openings (Rodewald and Yahner 2001). Distance-to-edge did not affect nest success for either disturbance type (Rodewald and Yahner 2001). Bayne and Hobson (1997) studied differences in nest success between landscapes of contiguous forest, managed (clearcut) forest, and forests fragmented by agriculture in central Canada. They found both edge and interior nests within the fragmented forest-agricultural landscape had significantly higher rates of loss compared to nests in clearcut and contiguous forest areas. Furthermore, there were no differences in nest loss between clearcut and contiguous forests (Bayne and Hobson 1997). Such observed differences in the effects of regeneration and agricultural openings may be at least partially explained by the work of Leimgruber et al. (2002), who found that the effects of even-age forest management (i.e. shelterwood) were not apparent on ecological process at the landscape scale – the scale most authors believe is suitable to identify nest predation and brood parasitism impacts (e.g., Robinson 1995, Donovan 1997, Rodewald and Yahner 2001). Many authors suggest the lower incidence of edge effects in managed forests relative to forests fragmented by agriculture is due to differences in predator assemblages and/or edge permanence between these two community types (Rudnicky and Hunter 1993, Lorimer 1994, Hanski et al. 1996, Bayne and Hobson 1997, Rodewald and Yahner 2001, Rodewald 2002).

Kaiser and Lindell (2007), working in highly agriculture-fragmented forests of central Michigan, studied edge effects in relation to fledgling growth, nest success, and productivity. They found wood thrush fledglings in nests close to clearcut edges had higher growth rates compared to fledglings in interior forest nests. No such relationship was found at field-forest edges, where fledgling growth rates were similar to those of interior forest. The authors suggest the "gradual edge" between mature forest and regenerating clearcuts offers better quality habitat for foraging adults which positively affects fledgling growth rates. Additionally, these authors found no significant distance-to-edge effects on nest survival or productivity in the fragmented forests they worked (Kaiser and Lindell 2007).

*Other Forest Management Practices and Activities*

In addition to the regeneration methods already discussed, practices such as intermediate cutting and prescribed burning are common forest management activities. Intermediate cutting is prescribed between regeneration periods to improve growth and development of crop trees (Thompson et al. 1993, Franklin et al. 2007). Thinning is a common intermediate method and may involve the removal of less desirable competitors from the understory or overstory. Unlike regeneration methods such as group selection and shelterwood, intermediate thinnings are primarily used to improve growing conditions, not encourage regeneration. Often trees are removed by cutting or girdling; when stump-sprouting is a concern, herbicide may also be applied (Thompson et al. 1993). In forests where fire historically played an important role as an agent of disturbance, prescribed burning has become an important ecosystem management and restoration tool (Thompson et al. 1996). Fire is often prescribed to favor the establishment of tree species that historically dominated fire-affected landscapes; in the Midwest, fire is often used to maintain disturbance-dependent communities such as savannas and open woodlands or to promote relatively fire-tolerant species, such as oaks and hickories, in closed-canopy forests (Brawn et al. 2001, Groninger et al. 2005, Dickinson 2006).

As with the effects of regeneration methods on songbird communities, research on intermediate cutting effects shows that impacts vary considerably by species. In Arkansas, Rodewald and Smith (1998) studied the effects of understory removal, alone and in combination with limited canopy reduction. They found abundance of worm-eating warblers, ovenbirds, and members of the understory-nesting guild were highest in mature, untreated forest; however, they found indigo buntings, white-breasted nuthatches, and members of the canopy-nesting guild to be most abundant in the two treatment sites where understory had been removed (Rodewald and Smith 1998). In Missouri, Wallendorf et al. (2007) studied the impacts of thinnings done in association with clearcutting on forest songbird territories. They found that sites near clearcuts that received thinnings were associated with a reduction in the number of Acadian flycatcher and ovenbird territories and an increase in the number of Kentucky warbler and indigo bunting territories (Wallendorf et al. 2007). They suggested canopy reduction in thinned sites may have affected Acadian flycatchers, while increased shrub-story growth may have impacted ground-nesting ovenbirds. However, they note a promotion of shrub-layer growth may have encouraged use by Kentucky warblers and indigo buntings (Wallendorf et al. 2007). Where ovenbird conservation is primary consideration, the authors suggest offsetting thinnings from clearcutting by 7 years, so canopy gaps created by thinnings could have time to close, making these areas attractive to ovenbirds for nesting at the time of clearcutting (Wallendorf et al. 2007).

Powell et al. (2000) studied wood thrush density, survival, and population growth in pine forests managed for the endangered red-cockaded woodpecker in Georgia. Management at these sites included pre-harvest thinnings and prescribed burning to reduce the hardwood midstory component of mature pine stands preferred by red-cockaded woodpecker. The wood thrush was chosen as a study subject because it commonly nests in hardwood tree species in the understory and there was concern its populations would be affected by management for the red-cockaded woodpecker. They found no evidence to suggest wood thrush density, survival, or population growth were reduced following thinnings or burning; in fact, their models predicted population growth on treated sites and simultaneous declines on control sites (Powell et al. 2000). They suggest wood thrush populations were not negatively impacted by the thinnings and burns because only a portion of the landscape was affected at any given time, allowing the highly mobile species to move into unaffected areas when necessary (Powell et al. 2000).

Interest in prescribed burning as a forest management and restoration tool has increased in recent decades, especially in oak ecosystems where there is concern for widespread oak declines, recruitment failures, and an increasing dominance of mixed-mesophytic species in forests historically dominated by oaks (*see* Spetich 2004). Prescribed fires may be of low- or high- intensity, depending on the objective of the burn. Low-intensity burns are the most common, and generally are limited to fuels of leaf litter and, to a lesser extent, the shrub-layer, causing little or no damage to the overstory (Brose et al. 2006). High-intensity prescribed fires are relatively uncommon and kill a significant number of overstory trees in addition to consuming litter and small diameter stems in the shrub-layer (Brose et al. 2006). Depending on the management objectives, fire can be applied in mature, uncut stands or following a harvest as regeneration is developing (Brose et al. 2006). Timing and periodicity of burns is highly variable as well; some sites are burned once, while others are burned annually or less frequently over a decade or more (Brose 2006).

Despite wide variation in how prescribed burning is practiced, some generalities regarding forest bird habitat are apparent from the research literature. As with other forest management activities reviewed, prescribed burning often provides temporary, short-term benefits to some species, while simultaneously reducing habitat suitability for others (Artman et al. 2001, Aquilani et al. 2003, Greenberg et al. 2007). Studies have typically detected reductions in ground- and low-shrub nesting species following prescribed fires, presumably because habitat conditions in these strata were significantly altered by burning (Artman et al. 2001, Aquilani et al. 2003, Greenberg et al. 2007). In Indiana, Aquilani et al. (2003) compared avian abundance in a recently burned (< 4 years) site with a nearby unburned site over a period of two years. They found species richness to be similar on the two closed-canopy sites; however, burned areas had a higher abundance of indigo buntings, scarlet tanagers, and white-breasted nuthatches, while the unburned site had a higher abundance of ground and shrub nesting species, such as ovenbird and Eastern towhee (Aquilani et al. 2003). They suggest the low-intensity fires may have affected overall community structure by benefiting species requiring snags and open understories, while reducing nesting habitat for those that nest on the ground or in shrubs; however, they caution that their data were scant and only reflect post-burn observations made over two breeding seasons (Aquilani et al. 2003).

Artman et al. (2001) studied the effects of low-intensity early-spring burns conducted frequently (annually) and infrequently (two years separating burns) over a 4 year period on closed-canopy sites. They found frequent repeated burning incrementally reduced leaf litter and the density of low shrubs and saplings, but with infrequent burning leaf litter recovered and exceeded pre-burn levels 2 years after the initial burn. Four of the 30 bird species studied experienced declines in abundance within burn areas (ovenbirds, worm-eating warblers, hooded warblers, and Northern cardinals); however, many individuals still continued to nest and forage in unburned vegetation within burned units and immediately around their perimeter (Artman et al. 2001). Eastern wood-pewee and American robins increased in density primarily due to increased foraging opportunities in burned areas (Artman et al. 2001). Though the authors found no overall change in the breeding bird communities on their study sites, they caution that long-term exposure to frequent (i.e. annual) burning could alter community composition (Artman et al. 2001).

Greenberg et al. (2007) studied the effects of moderate- to high-intensity fires that had been prescribed to reduce fuel loading and future wildfire risk in closed-canopy forests of North Carolina. The effectiveness of prescribed fire was tested along with the use of mechanical understory removal, individually and in combined treatments. While the density of many breeding bird species did not change after removals and burns, some ground and low-shrub nesting species experienced short-term declines in response to mechanical removals or combination treatments of removals and burns (Greenberg et al. 2007). Increases were observed in indigo buntings, Eastern bluebirds, and overall bird species richness and density in treated sites; the authors suggested this was in response to the higher snag availability, open understory, and elevated densities of flying insects which characterized these sites following burns and removals (Greenberg et al. 2007).

Artman and Downhower (2003) studied the nesting ecology and reproductive success of wood thrushes following early-spring low-intensity prescribed burns in Ohio.

Though habitat characteristics and the availability of nest substrate differed between burned and unburned locations, wood thrushes continued to nest in burned areas and nest success was similar in burned and unburned sites (Artman and Downhower 2003). Wood thrushes in this study showed flexibility in nest placement following burns by building nests higher in shrubs and trees in burned areas, which apparently allowed them to continue nesting in fire-affected sites despite other changes in habitat suitability (Artman and Downhower 2003).

## Conclusions and Management Recommendations

This literature review of the effects of silvicultural practices on eastern North American forest birds clearly demonstrates that no single method can provide suitable habitat conditions necessary for the conservation of all forest bird species. Where avian species diversity is a forest management goal, the most effective approach is to employ a variety of management techniques, tools, and alternatives across forested landscapes in such a way so as to provide for the habitat needs of all species.

In their review of major issues in the conservation of neotropical migratory landbirds in central hardwood landscapes, Thompson et al. (1996) reach a similar conclusion, stating "[w]e believe a mix of even- and uneven-aged silvicultural practices, designated reserve areas, and use of prescribed fire will be required within the Central Hardwood Region to meet bird conservation objectives and other objectives for forest lands." This opinion is typical of the broader ecosystem-based philosophies of modern forest managers, who plan for the conservation of non-timber resources in forest management prescriptions, including native plant and animal species and ecological processes (e.g., Freemark et al. 1993, Czech and Krausman 1997, Grumbine 1997, Franklin et al. 2007). Authors of the Partners in Flight Bird Conservation Plan for the Interior Low Plateau suggest a combination of uneven- and even-age silvicultural approaches to provide for the habitat needs of both late- and early-successional forest bird species (Ford et al. 2000). By using a variety of silvicultural practices across forested landscapes, managers increase heterogeneity among forest types and age classes, which has been shown to positively affect avian species diversity at landscape scales (Loehle et al. 2005, Mitchell et al. 2006). However, excessive heterogeneity and fragmentation among age classes can be detrimental and is likely to have a negative effect on avian richness (Ford et al. 2000, Mitchell et al. 2006). Careful planning and landscape evaluation is necessary to ensure age classes are appropriately distributed.

The silvicultural practices reviewed here are typically considered during many forest management activities; however, land managers will often need to consider issues that will require special management decisions and activities tailored to suit unique circumstances. For instance, land managers need to consider the special habitat requirements of conservation-priority species, such as those that are endangered or rare. Planning for unique habitats and species of greatest conservation need may require special limitations on management activities or a careful selection of compatible silvicultural practices (Thompson et al. 1996; e.g., Wallendorf et al. 2007). Additionally, land managers need to recognize that special habitat features often need to be retained at the stand level (DeGraaf and Shigo 1985, Tubbs et al. 1987, Franklin et al. 2007). Structural habitat resources such as snags and cavity trees are critical components of healthy, sustainable forest communities and should not be overlooked during planning. Guidelines for the retention of structural habitat resources should be considered regardless of the silvicultural practice used. Though the silvicultural methods reviewed here can provide predictable effects on bird species and forest communities in general, responsible forest managers will employ a comprehensive approach to forest management to consider and address the needs of all affected species and communities.

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