Accommodating Birds in Managed Forests of North America: A Review of Bird-Forestry Relationships[1]

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Abstract

Managed forests of North America provide important breeding and wintering habitat for many bird species. It is therefore essential that we understand all aspects of bird-forestry relationships if forest managers are to balance the needs of birds with timber harvest objectives. To help meet this need, here we provide a review of 116 research articles, dating from 1960 to 2002, which have examined bird-forestry relationships in managed forests across North America. We emphasize patterns in response of birds to silviculture, discuss how forestry practices might be used to enhance habitat for birds, synthesize management recommendations, and offer suggestions for future research. The majority of studies reviewed occurred in northeastern (27 percent) or northwestern (19 percent) North America. Clearcutting (72 percent of studies) has been examined more than any other silvicultural technique. Studies have primarily focused on breeding songbirds (67 percent) and have mostly collected data on relative avian abundance (65 percent); avian demographics (e.g., nest success or productivity) have rarely been studied (13 percent). The response of birds to forestry practices has been mixed and highly species-specific, but in general, net change in community richness following timber harvest was negligible. Among silvicultural practices, uneven-aged management (e.g., selection harvest) appears to be the most favorable for birds. In contrast, snag removal was highly deleterious, with >80 percent of studies reporting net species loss; net gain was never reported. Short-term effects (0–5 years) were more commonly found than no effect, with bird population decreases being reported more often than increases. In contrast, long-term effects (10+ years) were mostly negligible, but when effects were identified, they tended to be more beneficial than deleterious. Reports of severe deleterious effects were both rare and temporary. Causal mechanisms that might drive observed patterns between birds and forestry were deductively inferred in 72 percent of studies. Management recommendations were not made in the majority of cases (69 percent). Our review suggests that opportunities to enhance habitat for birds through forestry will vary from species to species. Management objectives, in addition to being compatible with ownership objectives, should be prioritized based upon those bird species that are sensitive to forestry and showing sharp declines. Future research on bird-forestry relationships needs to be more mechanistic, manipulative, and long-term. What is ultimately needed are resourceful ways to integrate stand- and landscape-level features created by forestry with those required by birds for sustained avian population health and viability.

Key words: causal mechanisms, cavity-nesting birds, community response, forest management, forestry practices, research needs, silviculture, songbirds, timber harvest

Introduction

North American forests provide important breeding and wintering habitat for many bird species (DeGraaf et al. 1991a, Rappole 1996). These forests are not only important to birds, but also provide wood products for an ever-expanding human population. Given increasing demands for such products, management of forests is inevitable and widespread. Approximately one-third of the U.S. land area is forested (298 million ha; Powell et al. 1993). Forests considered commercial timberlands capable of management for commodity extraction (henceforth "managed forests") comprise approximately 198 million ha, or two-thirds of all forest land in the U.S. Seventy-three percent (145 million ha) of these timberlands are privately owned and managed (116 million ha owned by non-industry landowners; 29 million ha owned by the forest products industry), while the remaining 27 percent are managed by public land-management agencies (Powell et al. 1993). Thus, it is crucial to understand bird responses to silviculture throughout managed forests of the U.S.

Research efforts to understand general relationships between forestry practices and bird populations have increased throughout the past quarter century (Sallabanks et al. 2000). These efforts have perhaps

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been driven by reports of declines in some migratory songbird populations (e.g., Robbins et al. 1989, Peterjohn et al. 1995). Research on bird-forestry relationships may be especially critical considering that approximately one-third of all migratory bird species are forest-dependent during one or more phases of their life cycle (Rappole 1996). Furthermore, permanent resident species may be even more dependent on managed forests than many Neotropical migrants because of their year-round use of such habitat. Indeed, evidence suggests that permanent residents, as a group, may be more strongly influenced by forestry practices than migratory species (Hejl et al. 1995).

We conducted a continent-wide review of studies that have examined bird-forestry relationships in managed forests across North America. Sallabanks et al. (2000) provided an evaluation of research on the effects of timber harvest on bird populations that focused on the kind of research that has been conducted, a critical assessment of its effectiveness, and suggested future directions. Here, we also characterize the nature of such studies (e.g., where conducted, in what habitats, which silvicultural techniques, and experimental design), but focus more on the response of birds to silviculture, examine relationships between birds and habitat features created by forestry, and synthesize management recommendations. Our review summarizes previous research, identifies key findings and trends, presents some unifying principles, and highlights information gaps and future research needs. Finally, we discuss how forestry practices might be used to enhance habitat for birds and offer suggestions on how avian conservation and timber production might become more complimentary.

Methods

We used two techniques to identify as many studies as possible that addressed relationships between forestry practices and bird populations in North America: (1) an extensive literature search which provided published studies in refereed scientific journals, USDA Forest Service publications (e.g., General Technical Reports, Research Papers, and Research Notes), and symposium proceedings; and (2) a letter sent to 23 forest products companies requesting reprints, submitted manuscripts, annual reports, and study proposals which yielded information on past studies, as well as those that were still ongoing or even planned for the near future. To be included in our review, studies must have been conducted within North America (48 contiguous United States, Alaska, Canada, and Mexico) and specifically address relationships between silvicultural practices and birds. University dissertations and theses were not considered. We did not include studies of forest fragmentation, patch size, or edge effects unless recent (last 25–30 years) silvicultural techniques were involved and well described (e.g., Schmiegelow et al. 1997). These topics have been recently reviewed elsewhere (e.g., Paton 1994, Faaborg et al. 1998). Neither did we include studies that described general bird-habitat relationships or behavior (e.g., foraging; Conner and Crawford 1974, Franzreb 1983), even if conducted in managed forests, unless direct references to forestry were discussed or implied. Modeling efforts that described simulated responses of birds to forestry practices also were omitted (e.g., Hansen et al. 1993, 1995a; Thompson 1993).

Our objective was to focus primarily on common breeding birds, especially passerines and cavity-nesters. We excluded studies of species listed as Threatened or Endangered, such as the Northern Spotted Owl (*Strix occidentalis*; Irwin et al. 1991, Meyer et al. 1998), Marbled Murrelet (*Brachyramphus marmoratus*; Courtney 1995, Nelson and Sealy 1995, Ralph et al. 1995), Northern Goshawk (*Accipiter gentilis*; Crocker-Bedford 1990, Finn et al. 1997), and Red-cockaded Woodpecker (*Picoides borealis*; Wood et al. 1985, Conner and Rudolph 1991; Conner et al. 1991, 1995). Finally, although they are silvicultural practices, we did not include studies of regeneration, site preparation, or animal damage control in our review. Instead, we chose to focus on those silvicultural techniques that involve manipulation of stand density and distribution. Studies of birds that involve forestry practices other than tree removal are rare (e.g., effects of herbicide and fertilizer treatments; see McComb and Rumsey 1983, Thiel 1987) and we urge that more focus be put on this important topic in the future.

All articles in our review were first classified by each of 22 study criteria and “scored” using a variety of classification “fields” (*table 1*). In most cases, the appropriate classification field was gleaned directly from the article being reviewed; in others, a simple reanalysis of available data was required, such as when calculating overall avian community response (*table 1, criteria no. 14*) if this had not been done by the original author(s). Usually, only one classification field could be listed per review criterion (e.g., the study was conducted in the northwest, but not in the northwest and the southeast). In some cases, however, multiple classification fields could be applied to the same study (e.g., studies that examined a variety of silvicultural techniques); in such cases, all fields that were appropriate were included in our analyses (see *Appendix 1* for a summary of field scores for all studies included in our review).

Table 1—*List of criteria used to classify literature on the effects of forestry practices on bird populations in managed forests of North America.*

No.	Review criteria	Classification fields
1	Geographical region of study	north (AB, MI, MN, NS, ON, WI); northwest (AK, BC, ID, MT, OR, WA); west (CA, CO, UT, WY); southwest (AZ); south (AR, TX); southeast (AL, FL, NC, SC); east (KY, MD, VA, WV); northeast (MA, ME, NH, NY, PA, PQ, VT); Midwest (MO)
2	Forest habitat	coniferous; hardwood; mixed coniferous-hardwood
3	Silvicultural prescription[1]	clearcut; group selection; shelterwood; single-tree selection; (pre)commercial thin; snag removal/retention; salvage logging
4	Prescription category	even-aged; uneven-aged; snag removal
5	Spatial scale of study	edge; stand; landscape/watershed
6	Study duration	number of years study was conducted (field seasons of data)
7	Pre-/post-treatment data	yes; no
8	Degree of replication	mean number of replicate experimental units per silvicultural treatment
9	Type of study	mensurative (i.e., observational/correlative); manipulative experiment
10	Bird species or nest type studied	breeding birds; wintering birds; year-round birds; cavity nesters; single species; real nest success; artificial nest predation
11	Data type collected	relative abundance; density; demographics (e.g., nest success, mist-netting, artificial nest studies)
12	Effects on avian abundance[2]	abundance increased; abundance decreased; no effect (no difference/change); mixed (e.g., breeding bird patterns ≠ winter bird patterns or relationships changed over time)
13	Effects on species richness (“richness” defined as number of species)[2]	richness increased; richness decreased; no effect (no difference/change); mixed (e.g., breeding bird patterns ≠ winter bird patterns or relationships changed over time)
14	Overall community response[2]	the number of species that increased in abundance > those that decreased; the number of species that increased in abundance < those that decreased; the number of species that increased in abundance = those that decreased
15	Effects on nest survival[2]	nest success increased; nest success decreased; no effect (no difference/change)
16	General effects of forestry[3]	minor; moderate; major
17	Short-term (0–5 years) effects[2]	increase in parameter measured (i.e., avian abundance, species richness, or nest success); decrease in parameter measured; no effect (no difference/change)
18	Long-term (10+ years) effects[2]	increase in parameter measured (i.e., avian abundance, species richness, or nest success); decrease in parameter measured; no effect (no difference/change)
19	Causal mechanisms identified	none; habitat features (e.g., snag density, understory structure, canopy cover); predators; food resources; physical features; landscape features
20	Vegetation data collected	yes; no
21	Bird-habitat relationships	yes; no
22	Management recommendations made	none; specific recommendations (e.g., leave snags, maintain light overstory, incorporate old growth features)

[1] “Single-tree selection” included “selective logging” and “best management practice cuts”; “(pre)commercial thinning” included “overstory removal”, “understory removal”, and “two-age” or “two-story cutting”. All other types of silviculture were as listed.
[2] Results include scores for only those studies where these criteria were applicable and/or analyzed.
[3] The general effects of forestry practices were determined by interpreting the magnitude of effects reported in each article, relative to all other articles included in the review (e.g., based upon the number of species responding to silvicultural treatments); this particular criterion is therefore a subjective, qualitative, and relative measure.

Results

Studies on Forestry Practices and Bird Populations

We reviewed 116 research articles dating from 1960–2002 that addressed effects of forestry practices on bird populations (*Appendix 1*). Studies were conducted throughout North America, but almost half occurred in either the northeast or the northwest (northeast, 27 percent [*n* = 31]; northwest, 19 percent [n = 22]; southeast, 11 percent [n = 13]; north, 10 percent [n = 12]; southwest, 9 percent [n = 10]; east, 9 percent [n = 10]; west, 9 percent [n = 10]; south, 4 percent [n = 5]; Midwest, 2 percent [n = 2]). Effects of management in coniferous forest (39 percent [*n* = 45]) have been studied more frequently than in hardwoods (32 percent [n = 37]) or mixed coniferous-hardwood forest (29 percent [n = 34]). The most common silvicultural system studied has been clearcutting, with 84 (54 percent) studies reviewed having some component that examined this particular method of timber harvest. Other silvicultural practices that have been examined include commercial thinning (21 percent [n = 33]), single-tree selection (11 percent [n = 17]), snag management (6 percent [n = 10]), group selection (5 percent [n = 7]), shelterwood cuts (2 percent [n = 3]), and salvage logging (1 percent [n = 1]). The spatial scale of studies was typically small, either being limited to the stand level (87 percent, n = 106) or forest edges (5 percent, n = 6). Landscape-level studies, where effects of forestry were examined at larger scales (e.g., watersheds), were rare (8 percent, n = 10), and have occurred relatively recently (all 10 studies were published since 1995).

Studies on bird-forestry relationships typically have lasted 1–2 years (expressed as the number of field seasons in which data were collected; for all studies, mean ± 1 SE = 2.35 ± 0.14); only six studies (5 percent) in our review reported data collected in more than four field seasons. The majority of studies were retrospective (i.e., data were not collected prior to timber harvest; 78 percent, n = 91); pre- and post-treatment comparisons were therefore limited (22 percent, n = 25). Replication of experimental units was low. Most studies (26 percent, n = 30) had only one replicate per treatment (for all studies, mean ± 1 SE = 5.55 ± 1.49). All studies in our review were mensurative (observational or correlational); none incorporated a manipulative experimental design where treatments were randomly assigned to experimental units (Hurlbert 1984).

With respect to which species of bird were typically studied, breeding birds (primarily songbirds) were the norm (67 percent [n = 80]). Others included year-round residents (13 percent [n = 15]), artificial nests (7 percent [n = 8]), real nest success (4 percent [5]), cavity nesters (4 percent [5]), single species (3 percent [n = 3]), and wintering birds (2 percent [n = 2]). Finally, the majority of studies on bird-forestry relationships collected data on relative avian abundance (primarily using point counts; 65 percent, n = 78), rather than density estimates (primarily from spot-mapping; 22 percent, n = 27) or demographics such as nest success, rates of nest depredation, or productivity (primarily from nest monitoring, artificial nest experiments, or mist-netting; 13 percent, n = 16).

Effects of Forestry Practices on Birds

Avian Abundance

Seventy-nine percent (n = 92) of studies provided data that allowed us to classify them with respect to effects of forestry practices on avian abundance (typically measured as relative abundance or density, but basically reflecting numbers of individual birds). In general, all forestry practices considered together tended to result in more decreases in avian abundance (32 percent, *n* = 29 studies) than increases (24 percent, n = 22 studies). Twenty-six percent (n = 24) of studies found no changes in abundance; eighteen percent (n = 17) of studies found "mixed effects" (e.g., abundance increased for breeding birds, but decreased for wintering birds). When the silvicultural method being studied was snag removal (n = 5), decreases in abundance always were reported.

Species Richness and Compositional Changes

Seventy-four percent of studies (n = 86) reported changes in species richness (numbers of species) in response to forestry practices. Richness decreased in 33 percent (n = 28) of studies, increased in 27 percent (n = 23), and remained unchanged in 26 percent (n = 22). In 15 percent of studies (n = 13), response of species richness to forestry practices was mixed (i.e., breeding bird responses differed from wintering bird responses and/or responses changed over time). Overall avian community response (number of species increasing in abundance vs. number decreasing) to forestry practices was determined for 78 percent (n = 91) of studies. Although 43 percent (n = 39) of studies found more species decreased than increased, an equal number (42 percent, n = 38) found more species increased than decreased; 15 percent (n = 14) found the number of species increased to be equal to the number decreased. When analyzed with respect to silvicultural method, overall community response was negligible for even-aged management, more species increased than decreased for uneven-aged management, and many more species decreased than increased for snag removal.

Nesting Success

Relationships between nest success (or predation rate) and forestry could be assessed for 14 of 16 studies that collected demographic data. In response to forestry, reduced rates of nest success were more commonly reported (42 percent, n = 6) than increased rates (29 percent, n = 4) or no effects (29 percent, n = 4). Approximately half of the studies that examined nest success did so using artificial nest experiments which have been criticized in the scientific literature (see Discussion). With respect to responses to forest practices, however, results from artificial nest experiments were qualitatively the same as those from studies of real nests.

Magnitude of Effects

General effects of forestry practices were determined by interpreting the magnitude of effects reported in each article, relative to all other articles included in our review; this particular criterion is therefore a subjective, qualitative, and relative measure. If, for example, relatively few species were affected, or changes in avian abundance, richness, community composition, or nest success were relatively minimal, general effects of forestry were scored as being "minor." If, on the other hand, relatively large numbers of species were affected or changes were relatively severe (e.g., some species disappeared altogether), general effects were scored as "major", and so on. In this way, we found most studies to report "moderate" (48 percent, n = 56) to "minor" (44 percent, n = 51) effects; "major" effects were rarely reported (8 percent, n = 9). For nine studies classified as having "major" effects, most (n = 6) documented decreases in the avian population parameter being measured; half of these (n = 3) were in relation to intermediate cutting prescriptions (again, snag removal *per se*).

Duration of Effects

Short-term (0–5 years) vs. long-term (10+ years) effects of forestry practices on bird populations were assessed for 38 percent (n = 44) of studies; some examined short- or long-term effects, and some both. The majority of these results are based on reported changes in bird abundance and species richness (only four studies of nest success addressed short- vs. long-term effects). Short-term effects were found more commonly than no effect, with population decreases ("deleterious" effects; 50 percent, n = 23) being reported more often than increases ("beneficial" effects; 33 percent, n = 18). In contrast, long-term effects were mostly negligible (62 percent, n = 23), but when effects were identified, they were more beneficial (24 percent, n = 9) than deleterious (14 percent, n = 5).

Mechanisms Driving Bird-Forestry Relationships

Causal mechanisms (proximate factors) that might drive observed relationships between birds and forestry were deductively inferred in 72 percent (n = 84) of studies included in our review. Proximate factors (e.g., habitat structures) are assumed to lead to changes in ultimate factors (e.g., nest site or food availability) that can directly influence population viability of birds. Habitat structure, such as understory cover or tree stocking density, do not directly affect avian productivity (i.e., number of young produced per nest) and are therefore considered proximate factors or mechanisms. On the other hand, predator density and food availability, which may be driven by habitat structure, clearly have the potential to directly influence avian fitness and are therefore considered ultimate factors or mechanisms. Ultimate factors are rarely discussed in studies of bird-forestry relationships. In our review, the most frequently suggested proximate mechanism for bird responses to forestry was change in habitat structure (53 percent, n = 64). Of those studies that did list habitat structure as the reason for changes or responses of birds to forestry practices, 42 percent (n = 27) did not give measured details on specific variables. Of those that did, snag density (18 percent, n = 16), understory structure (16 percent, n = 15), and canopy cover (9 percent, n = 8) ranked highly. Many studies (60 percent, n = 70) did collect data on habitat characteristics, yet only a subset of these (22 percent, n = 25) used the data to interpret bird-forestry relationships.

Management Recommendations

Specific management recommendations were not reported in the majority of cases (69 percent, n = 80). When management recommendations were suggested, they were highly variable and case-specific. The most common recommendations were to leave and/or create snags (24 percent, n = 15), leave uncut reserves and maintain residual old growth clumps (13 percent, n = 8), incorporate features of old growth forest into younger stands (8 percent, n = 5), enhance vegetative diversity (especially in the understory) by creating light gaps (8 percent, n = 5), and retain large contiguous forest tracts with few openings (i.e., minimize forest fragmentation; 8 percent, n = 5).

Discussion

Much has been learned about relationships between birds and forestry since research began on this subject almost four decades ago with the work of Hagar (1960). Studies have occurred in all major forest types (coniferous, hardwoods, and mixed coniferous-hardwood), and most efforts have focused in the northeastern and northwestern regions of North America. Overwhelmingly, effects of clearcut harvesting on birds have been studied more than any other form of forest management. Moreover, these studies have been short-term and conducted at the stand level. Historically, clearcutting has been the predominant method by which to harvest timber. Whereas the current trend is a decline in use of clearcut harvesting on federal lands (G. Lettman, Oregon Dept. Forestry, pers. comm.), this silvicultural practice will likely continue to be very important on private lands, which comprise the bulk of managed forest in the U. S. (Powell et al. 1993). To continue conducting research that is of highest relevance to forest managers, it is important to consider which silvicultural techniques are currently being practiced when designing research projects. One way to ensure that experimental treatments being studied will have relevance to current forest management is to include managers during development of research projects (Finch and Patton-Mallory 1993, Arnett and Sallabanks 1998).

Effects of Forestry Practices on Bird Populations

Combining results from all studies (i.e., disregarding the silvicultural prescription examined), effects of forestry practices on birds have been very mixed, but generally have resulted in few net changes in either avian abundance (number of birds) or species richness (number of species). Approximately one-quarter of studies report no response. Because most silvicultural treatments will benefit some species and not others, management for high avian "biodiversity" may be a hollow goal (Hansen et al. 1995b). Thus, it seems prudent that management objectives to enhance habitat for birds should be specific and driven by the highest priority species in the region. Partners in Flight (PIF) priority species scores (Carter et al. 2000) could possibly be used to identify focal species. To facilitate their implementation, avian conservation strategies should consider perspectives and management objectives of private landowners as well as public land-management agencies.

Effects of forestry on birds therefore appear to be more meaningfully evaluated if done at the species level rather than the community level. Without exception, all studies included in our review reported mixed results with respect to individual species' responses: some birds either increased post-harvest or were more abundant in logged habitat, others either decreased post-harvest or were less abundant in logged habitat, while still others were unaffected. The magnitude and direction of these relationships varied across studies, even within species, often depending upon the forestry practices employed, region and habitats examined, duration, and season of study. In order to summarize these relationships, the number of species increasing was compared to the number decreasing for all possible studies. The results were almost identical and suggest that for every species negatively impacted by forestry, one is positively impacted, and vice versa. This result further emphasizes the need for species-specific management strategies in combination with general efforts to improve forest habitat for all birds. In addition, these results suggest that a variety of habitats, or a wide range of variation in key habitat structures, is necessary to support entire bird communities. Our review also demonstrated that effects at one spatial scale can be quite different from those at another. Thus, while stand-level abundance can decrease for a species, forest managers actually might have opportunities to increase abundance for that species at a larger spatial scale.

Although our review indicates that no forestry technique will benefit all species, uneven-aged management practices (i.e., single- and group-tree selection) did result in a greater number of species showing population increases than decreases, as compared with even-aged prescriptions such as clearcutting and shelterwood cuts. What seems to be particularly detrimental to forest avifauna is removal of snags. When prescriptions involved manipulation of snag densities, either by removing (Kilgore 1971, Scott 1979, Dingledine and Haufler 1983, Scott and Oldemeyer 1983, Schreiber and deCalesta 1992), retaining (Dickson et al. 1983, Zarnowitz and Manuwal 1985, Stribling et al. 1990, Schreiber and deCalesta 1992, Welsh et al. 1992), or creating (McPeek et al. 1987) snags, bird numbers were typically found to be positively correlated with snag density. Unlike even-aged and uneven-aged management practices, removal of snags never resulted in more species increasing in abundance than decreasing. The importance of snags to birds is well-known (Davis et al. 1983 and references therein, Bull et al. 1997, references above), not only to cavity nesters, but also songbirds (Sallabanks et al. 2002) that may use snags for nesting, perching, foraging, singing, and scanning for predators.

Effects of Forestry Practices on Bird Species

Species-specific responses to forestry are obviously highly variable and difficult to summarize given the broad geographical range of studies included in our review. Using representative studies, however, here we offer some generalizations about which species exhibited significant responses to a variety of silvicultural techniques. In Maine, for example, Derleth et al.

(1989) found the White-throated Sparrow (*Zonotrichia albicollis*), Common Yellowthroat (*Geothylpis trichas*), American Robin (*Turdus migratorius*), and Common Grackle (*Quiscalus quiscula*) to be more abundant in clearcut areas than the surrounding forest edge. These are species well-known to use patchy or early successional habitat (see also Webb et al. 1977 and Titterington et al. 1979). The Red-breasted Nuthatch (*Sitta canadensis*) and Cape May Warbler (*Dendroica tigrina*) were two species found to be intolerant of forest openings and adjacent forest edges in Maine (Derleth et al. 1989). Like Townsend's Warbler (*Dendroica townsendi*) in the west (Sallabanks et al. 2002), these species appear to favor dense forest stands with closed canopies.

In response to fuelwood cutting in southern New England, the Ovenbird (*Seiurus aurocapillus*), Hermit Thrush (*Catharus guttatus*), and Wood Thrush (*Hylocichla mustelina*) decreased in number (Chadwick et al. 1986). More species were found in cut stands than uncut stands, however, and included the Spotted Towhee (*Pipilo erythrophthalmus*), Common Yellowthroat, Blue Jay (*Cyanocitta cristata*), Black-and-white Warbler (*Mniotilta varia*), and Chestnut-sided Warbler (*Dendroica pensylvanica*). Bird communities of uncut stands were dominated by species that prefer mature, closed-canopy forests and by cavity nesters (Chadwick et al. 1986).

In the southwest, Szaro and Balda (1979) found species such as the White-breasted Nuthatch (*Sitta carolinensis*), Grace's Warbler (*Dendroica graciae*), Chipping Sparrow (*Spizella passerina*), Broad-tailed Hummingbird (*Selasphorus platycercus*), and Western Bluebird (*Sialia mexicana*) to have their highest population densities in treated plots, indicating density increases in response to openness. In contrast, numbers of Red-faced Warbler (*Cardellina rubrifrons*), Pygmy Nuthatch (*Sitta pygmaea*), Cordilleran Flycatcher (*Empidonax occidentalis*), Violet-green Swallow (*Tachycineta thalassina*), and Black-headed Grosbeak (*Pheucticus melanocephalus*) were significantly reduced as intensity of timber harvest increased (e.g., heavily thinned and clearcut treatments).

In the Douglas-fir (*Pseudostuga menziesii*) region of northwestern California, Hagar (1960) found the following seed-eating birds to increase in number in response to clearcutting: Dark-eyed Junco (*Junco hyemalis oreganus*), Spotted Towhee, Mountain Quail (*Oreortyx pictus*), Golden-crowned Sparrow (*Zonotrichia atricapilla*), and Fox Sparrow (*Passerella iliaca*). Edges were used by the Red-breasted Nuthatch and Chestnut-backed Chickadee (*Parus rufescens*) although these species responded negatively to cutting practices in general. Other species found to have lower abundance in "cutovers" compared with old growth forest included the Hermit Thrush, Golden-crowned Kinglet (*Regulus satrapa*), and Pileated Woodpecker (*Dryocopus pileatus*).

Several studies that specifically addressed snag manipulations identified several cavity-nesting birds that had lower numbers in areas without snags. In Arizona, these included the Northern Flicker (*Colaptes auratus*), Violet-green Swallow, and Pygmy Nuthatch (Scott 1979, Scott and Oldemeyer 1983); in Texas, these included the Great Crested Flycatcher (*Myiarchus crinitus*), Red-headed Woodpecker (*Melanerpes erythrocephalus*), Downy Woodpecker (*Picoides pubescens*), Red-bellied Woodpecker (*Melanerpes carolinus*), Hairy Woodpecker (*Picoides villosus*), and Carolina Chickadee (*Parus carolinensis*) (Dickson et al. 1983). Clearly, dependency of cavity nesters on snags is one reason why silvicultural methods that include prescriptions for snag removal have more profound effects on birds than others that do not target snags *per se*.

Due to the high degree of species-specific variability in relationships with forestry, guild-level responses (although variable themselves) may be a more useful way to summarize which species are likely to benefit and which are not. Among foraging guilds, for example, granivorous and ground-gleaning species are likely to benefit from forestry practices because of the general increase in ground cover and associated food resources (Franzreb and Ohmart 1978, Szaro and Balda 1979, Maurer et al. 1981, Blake 1982, DeGraaf et al. 1991b, Tobalske et al. 1991). Aerial feeders also may benefit due to an increased ability to maneuver beneath forest canopies (Franzreb and Ohmart 1978, Szaro and Balda 1979; but see Maurer et al. 1981, Scott et al. 1982). Foliage- and timber-gleaners are likely to be the most adversely affected by forestry, presumably due to a reduction in foraging substrates (leaves and bark, respectively) and therefore fewer insects (Franzreb and Ohmart 1978, Maurer et al. 1981, Scott et al. 1982, Medin 1985, Medin and Booth 1989, Tobalske et al. 1991, Probst et al. 1992; but see Szaro and Balda 1979, McPeek et al. 1987, Norton and Hannon 1997).

Analyses of nesting guilds clearly show cavity nesters to respond negatively to logging, especially snag removal (Scott 1979, Szaro and Balda 1979, Scott and Oldemeyer 1983, Medin 1985, Zarnowitz and Manuwal 1985, Medin and Booth 1989, Johnson and Brown 1990, Greenberg et al. 1995; but see McComb et al. 1989, Welsh et al. 1992). Shrub nesting species are more likely to benefit from forestry practices that create light gaps, open up the overstory, and promote development of the herbaceous layer (Hallock 1989–1990; but see Norton and Hannon 1997). Results for ground (Medin 1985, Hallock 1989–1990, Tobalske et al. 1991, Norton and Hannon 1997) and canopy (Szaro and Balda 1979, Greenberg et al. 1995, Norton and Hannon 1997) nesters appear to vary with management intensity.

Effects of Forestry Practices on Avian Reproductive Success

Forestry practices appear to have a greater impact on bird populations when nest success is considered rather than relative avian abundance or density. All studies (n = 16) of nest success included, at least in part, an examination of effects of clearcut harvesting. Because few nest studies have been conducted, however, our synthesis of results from this research should be treated cautiously. Moreover, half (n = 8) of the “nest success” studies included in our analyses were studies of artificial nests rather than real nests (Yahner and Scott 1988, Yahner et al. 1989, DeGraaf and Angelstam 1993, Rudnicky and Hunter 1993, DeGraaf 1995, Yahner and Mahan 1996a, Darveau et al. 1997, and Manolis et al. 2000). Results from such studies, while certainly of high utility, may not reflect true rates of nest success and may provide misleading information with respect to predation rates and predator identification for several reasons (Wilson et al. 1998). For example, artificial nests lack parental defense of eggs and young. Moreover, all of the above eight studies used either chicken, Common Quail (*Coturnix coturnix*), or Northern Bobwhite (*Colinus virginianus*) eggs in their artificial nest experiments. Use of large, artificial eggs has been criticized because they may be too large for certain nest predators (small mammals such as mice, squirrels, and chipmunks) to handle (Reitsma et al. 1990; Roper 1992; Haskell 1995a, 1995b; DeGraaf and Maier 1996; Yahner and Mahan 1996b).

In future research on this important topic, we encourage use of smaller eggs, such as those of the House Sparrow (*Passer domesticus*), that more realistically mimic egg size of ground and low-shrub nesting songbirds. Of eight artificial nest studies conducted, four found nest success to be lower in harvested plots (Yahner and Scott 1988, Yahner and Mahan 1996a, Darveau et al. 1997, Manolis et al. 2000), and three found negligible differences (Yahner et al. 1989, DeGraaf and Angelstam 1993, DeGraaf 1995). The only exception was the study of Rudnicky and Hunter (1993), who found success rates to be lower for nests placed in the forest compared with those placed in young, regenerating stands that were clearcut harvested 3–10 years prior to data collection.

When real nests were monitored, impacts of forestry practices on nest success were again found to be variable. Barber et al. (2001) found that only three of nine species differed with respect to nesting success among silvicultural treatments in managed forests of the Ouachita Mountains, central Arkansas. In general, many species had nest success rates equal to or greater than those in previously published studies (most of which had occurred in unmanaged forests). Barber et al. (2001) found nesting success to be lowest in thinned stands (3–7 years post-thinned; 17–23 years old) for most nesting guilds due to high predation rates. This result could potentially be due to an abundant understory, which might support mammalian and reptilian predators. Thinned stands also had been pruned of lower limbs, therefore resulting in copious open space between the understory and the bottom of tree crowns. This could potentially have aided avian predators in their hunting and/or Brown-headed Cowbirds (*Molothrus ater*) in their searching.

Similar to Barber et al. (2001), Manolis et al. (2000) found thinned, even-aged, regenerating stands (mean age = 11.3 years) had greater nest predation rates. While Duguay et al. (2000) also found nest success to be higher in unharvested forest stands, no differences were found between clearcut (even-aged, regenerating stands, approximately 15 years old) and two-age (deferment) harvesting prescriptions. King et al. (2001) found no differences between clearcut and group selection prescriptions, but did report high survival rates in plots that had been clearcut harvested (4–5 years prior to data collection). In Oregon, Arnett et al. (2001) found that nest success in general was similar in salvage-logged stands of lodgepole pine (*Pinus contorta*) compared to unmanaged stands. Finally, Yahner (1991) found nest success to be independent of stand age (time since clearcut) and distance from clearcut edge.

Differences between results of studies relying upon artificial nest experiments and those monitoring real nests may exist if predator assemblages between harvested and unharvested forest also differ. If for example, relative to numbers of avian predators, small mammals (e.g., squirrels) are more abundant in forested habitats than regenerating stands, artificial nest experiments may find higher predation rates in the latter and erroneously conclude that clearcutting is deleterious with respect to songbird populations. Clearly, more studies of effects of forestry practices on avian reproductive success and population viability are needed.

Mechanistic Relationships

To improve habitat for birds via forestry requires that we understand why a factor (e.g., overstory removal) causes a response (e.g., change in avian nest success); such processes are determined by mechanistic relationships (Marzluff et al. 2000). There are both proximate and ultimate mechanisms that may drive changes in bird populations responding to forestry practices and distinguishing between these two is important for making accurate management recommendations. Nest-site availability (Martin 1993a, 1993b, 1995) and food availability (Martin 1987, 1995) are two ultimate mechanisms influencing health and viability of bird populations. Both of these forces will be driven by proximate mechanisms, such as changes in forest structure and/or landscape composition. Timber harvest will change forest stand structure in specific ways (e.g., reduction of overstory, reduction in total basal area, changes in stand structural heterogeneity, short-term reduction of understory vegetation, and long-term increase in understory vegetation) that may influence availability of safe nest sites for songbirds and/or cause changes in resident insect populations (the primary food for forest-breeding bird species; see Duguay et al. 2000). Changes in nest-site availability may lead to changes in nest predation rates and, therefore, avian fitness. Similarly, changes in insect populations may drive concurrent avian fitness changes if food availability is a more important mechanism than safe nest-site availability in determining nest success (e.g., Burke and Nol 1998, Robinson 1998). In many cases, it may be difficult to identify factors or mechanisms directly influencing effects of forestry on bird populations. Numerous studies, for example, have found correlations between seral stage and avian abundance or species richness, and then used these relationships to discuss causal effects. Unfortunately, cause and correlation are not the same thing, and indirect factors apparently influencing bird populations have limited use, especially when making predictive statements about effects of a proposed harvest prescription.

Unless direct mechanisms (both proximate and ultimate) are identified, causal relationships cannot be understood and management recommendations will be severely limited (Marzluff et al. 2000). Our review indicated that potential mechanisms were deductively inferred in most cases (72 percent), but many constituted general statements about habitat structure (27 out of 64 articles). Specific habitat features were not described in many cases, which again offers little to forest managers. When specific structural characteristics were mentioned, snag density and features of the understory were most frequently cited. We remain somewhat perplexed as to why most researchers took time to collect habitat data (60 percent), but then rarely (22 percent) used them to better interpret bird-habitat relationships.

In only a few cases were specific bird-habitat relationships modeled using statistical procedures such as multiple regression (e.g., Titterington et al. 1979; Monthey 1983; Yahner 1986, 1987a; Hagar et al. 1996; Karriker 1996; Rogers et al. 1996). Such models are useful for identifying specific causal mechanisms and developing subsequent management guidelines. It is important to note that numerous studies that were not included in this review, because they were primarily concerned with describing bird-habitat relationships and not effects of forestry practices *per se*, also provide information which is highly pertinent to this discussion (e.g., Conner et al. 1975, Crawford et al. 1981, Kerlinger and Doremus 1981, Briggs et al. 1982, Niemi and Hanowski 1984, DeGraaf and Chadwick 1987, Dessecker and Yahner 1987, Yahner 1987b, Raphael 1991, Adams and Morrison 1993, Hansen et al. 1995b, and Bosakowski 1997).

Opportunities for Creating Habitat for Birds

Forest management practices and changing land-use patterns have reduced the abundance, distribution, and recruitment of snags in managed forests in several regions of the U.S. (e.g., Thomas et al. 1979, Cline et al. 1980, McComb et al. 1986, Land et al. 1989, Ohmann et al. 1994, Lewis 1998). To comply with State forest practices laws, coupled with the advent of habitat conservation planning as outlined in section 10 of the Endangered Species Act (Lewis 1998) and other landscape habitat management planning efforts (e.g., Sustainable Forestry Initiative, American Forest and Paper Association), landowners and land management agencies have undertaken efforts to maintain and create snags, or provide future snag resources through green-tree retention. Numerous methods for creating snags and wildlife trees exist and could provide suitable habitat for cavity- and snag-using wildlife (Lewis 1998). Chambers et al. (1997) suggested that creating snags by topping may retain or increase populations of cavity nesters in areas with low natural snag density. Green-tree retention strategies have advanced to include prescriptions that can vary the level and spatial pattern of retained trees to achieve specific objectives, such as mimicking the effects of natural disturbance (Lehmkuhl et al. 1999). Since large remnant snags and "defective" residual green trees provide much of the snag habitat for cavity-nesters in early- to mid-successional stands, particularly on private lands (Ohmann et al. 1994), retention of these structures will be important for maintaining populations of cavity- and snag-using avian species in managed forests. Snag retention and/or creation were the most commonly listed management recommendations from studies included in our review. We concur that leaving snags wherever possible is another important way that foresters can improve or maintain avian habitat quality within managed forest landscapes. We recommend additional research to understand avian response to snag densities and distributions (at both stand and landscape scales) to maintain viable populations of avian species, particularly cavity-nesters. Furthermore, studies addressing effectiveness of snag creation (e.g., Chambers et al. 1997, Arnett 1998), foraging habitat requirements (Weikel and Hayes 1999), and green-tree retention strategies (e.g., Lehmkuhl et al. 1999) are warranted.

Fuelwood cutting has not been found to adversely affect songbird populations, but may be detrimental to cavity nesters (Dingledine and Haufler 1983, Chadwick et al. 1986). Instances of large-scale snag removal occur primarily in the form of salvage logging following stand-replacement wildfire. Salvage logging typically influences vegetative structure by removing snags and down wood, and can represent either even-aged (i.e., most or all trees removed from a stand; e.g., Saab and Dudley 1998) or uneven-aged (i.e., retention of varying densities of snags and/or green trees; e.g., Arnett et al. 2001). Relationships between forest avifauna and salvage logging are poorly understood and limited to only a few studies (Overturf 1979, Moeur and Guthrie 1984, Arnett et al. 2001, R. Sallabanks, unpubl. data). Bird response to different approaches to salvage logging and opportunities to maintain habitat structure for birds warrants further investigation.

Shrub abundance is known to be directly influenced by forestry practices (Beck 1985), yet most studies in our review paid little attention to this potentially important source of structural variation within managed forest stands. In the Pacific Northwest, shrub cover has been found to be extremely important to forest songbirds, especially Neotropical migrants; over 80 percent of shrub-nesters in this region are migrants (Bunnell et al. 1997). Forestry practices directly alter overstory conditions, which in turn influence dynamics of the understory, as light and moisture gradients change. Most researchers, when studying effects of forestry on birds, therefore tend to focus on collecting overstory habitat data, at the expense of data on understory structure and composition. We are concerned that vegetation sampling may lack sufficient rigor and intensity to adequately describe understory conditions for birds. Measures of shrub patch dynamics, height and layering of understory canopies, species identification of shrubs, forbs, and grasses, and even canopy cover by major understory strata are rarely made. To significantly improve our understanding of relationships between birds and forestry, we conclude that additional research is needed on overstory-understory dynamics (e.g., Johnson et al. 1993), and the interactions between these dynamics and shrub-nesting birds in managed forests.

Many studies, especially those that did not describe potential causal mechanisms, such as habitat structure, simply did not collect data necessary for specific management implications to be assessed. In the future, we encourage authors to end research articles with a discussion of management implications derived from their work. We stress that such discussion should take the form of potential implications and relevance for management opportunities to maintain or create habitat structure for birds, rather than listing specific management recommendations *per se*. Quite often, researchers are tempted to make recommendations beyond the scope of their data, which can be counterproductive. Most studies (69 percent) did not make specific management recommendations. Understandably, when recommendations were made, they were very case-specific and perhaps only relevant to the forests and birds in question. Generalized guidelines are difficult to make and may even be dangerous if applied elsewhere to other systems (Young and Varland 1998). For these same reasons, our ability to offer specific management recommendations based upon results of our review is limited. We caution that, because of the breadth of our review, which included all forest types, all forestry practices, and all regions of North America, our suggestions on how to enhance bird habitats through forestry also are broad.

Suggestions for Future Research

Study Design Considerations

Designing and implementing rigorous field experiments (i.e., those that are well-replicated, include treatment groups randomly assigned to experimental units, and gather pre- and post-treatment data; Hurlbert 1984) is notoriously difficult to accomplish (Underwood 1997), and research on effects of forestry practices on bird populations is no exception. To the extent possible, future studies of relationships between timber harvest and bird populations need to be more mechanistic, manipulative, and long-term in their approach. Sallabanks et al. (2000) provided a critical review of studies addressing effects of forestry practices on birds and offered suggestions for future research. Here, we synthesize key concepts and approaches for researchers to consider when designing studies to address the effects of forestry practices on birds.

Most studies in our review were not rigorously designed (i.e., they were descriptive, observational, appeared to have low statistical power [Steidl et al. 1997, Gerard et al. 1998]), and inferences about specific effects of forestry were limited and deductive at best. By incorporating more rigor to experimental design (e.g., replication, randomization), researchers can reduce or eliminate such factors affecting the interpretation of findings. Studies of bird-forestry relationships with little replication have low statistical power (Cohen 1988) and therefore are prone to concluding that a particular silvicultural treatment did not have an effect when in fact it did (Type II error; Zar 1996). Few studies in our review had more than four replicates per treatment, with the majority having only one. With only one replicate in a treatment, researchers have no way of knowing whether results that they report are representative of that treatment or not. Other local factors (e.g., aspect, slope, elevation, or juxtaposition with other forest stands) may have more bearing on bird communities found on a site than silvicultural treatments in question (e.g., Irwin 1998). Studies with only one replicate per treatment very likely were guilty of pseudoreplication (Hurlbert 1984), and interpretations from these studies should be viewed cautiously.

Few (22 percent) studies in our review incorporated pre- and post-treatment data (i.e., they were retrospective), and all studies were mensurative, where treatment groups were not randomly assigned to experimental units (replicates). Snag creation research (Arnett 1998), green tree retention (Lemkuhl et al. 1999), and bird response to thinning in Douglas-fir forests (Hayes et al. 2003) are the only manipulative studies we are currently aware of. An inherent problem associated with "observational" or "correlative" studies is that statistical inference is limited simply to differences among physical locations or points in time and is not relative to treatment effect (Hurlbert 1984, Heffner et al. 1996). Because observational studies provide only deductive and indirect inferences about relationships between forestry and birds, causal mechanisms underlying changes in bird communities following timber harvest cannot be directly determined. Studies in our review that suggested cause-and-effect relationships did so based on correlations. Romesburg (1981) noted that the history of science is replete with strong pronouncements of cause-and-effect based entirely on correlations. We agree with Romesburg (1981) that those studies where correlations are the sole evidence offer weak support for determining causal mechanisms relative to treatment effects. Forest managers need reliable information about mechanisms if they are to improve forest habitat for birds (Marzluff et al. 2000).

We suggest that future research on effects of forestry practices on bird populations utilize the hypothetico-deductive scientific method described by Romesburg (1981), and incorporate manipulative experiments where treatments are randomly assigned to experimental units. Random assignment of treatment provides an "unbiased" experiment that generally guarantees independent distribution of errors, thereby allowing for objective statistical testing of treatment effects (Hurlbert 1984). Furthermore, recent articles suggest the use of more informative and practical analytical methods such as confidence intervals or Bayesian methods (Steidl et al. 1997, Gerard et al. 1998). These approaches may offer greater insight to the practical importance and magnitude of a potential treatment effect than traditional hypothesis testing and, thus, may better guide management decisions (Steidl et al. 1997). Information-theoretic approaches to modeling (e.g., Burnham and Anderson 1998) have become popular in recent years and appear useful toward developing more meaningful models that reduce the potential for spurious results (Anderson et al. 2001). We therefore encourage researchers to explore these approaches when designing studies of bird-forestry relationships.

Temporal and Spatial Scale

If birds are found to respond to forestry, it seems imperative that we understand how long these effects remain. Studies in our review also were short-term, however, with data often only being collected during one to two field seasons. By far the longest study has been that of Webb et al. (1977), who surveyed breeding bird populations in a northern hardwood forest subjected to different logging intensities for ten consecutive seasons. Effects of forestry may be long-lasting (20+ years), or short-term (one to three years), but will remain ambiguous without studies that last longer than one to two years. Past research is characterized not only by small temporal scales, but small spatial scales as well. Landscape-level studies were rare and have been a relatively recent phenomenon (e.g., Hagan et al. 1995, 1996, 1997; Tappe 1996; Schmiegelow et al. 1997).

Response of Birds to Forestry Practices

Based upon results from our review, studies have focused heavily on relationships between forestry practices and breeding songbirds; wintering bird populations (i.e., permanent resident species) were surveyed in only 14 percent (n = 17) of studies. This result is biased by our decision to exclude studies of certain species (e.g., Threatened or Endangered species) from our review, but nevertheless illustrates the relative focus on breeding populations compared to wintering populations. Several factors have likely contributed to this bias: (1) relative to wintering birds, breeding songbirds are more easily sampled using standard point count surveys (Ralph et al. 1993); (2) field conditions are generally more conducive to collecting field data during spring and summer months; (3) more species are typically present during the breeding season, thereby seeming more cost-effective than sampling depauperate avian communities in winter; and (4) analyses of Breeding Bird Survey (BBS) data suggest that some migratory species, those only present during the breeding season in temperate North America, may be in decline (e.g., Robbins et al. 1989, Peterjohn et al. 1995). The lack of studies on wintering birds is rather alarming, especially in light of recent analyses by Hejl et al. (1995) that suggest permanent resident species in the northern Rocky Mountains are more adversely affected by silviculture than Neotropical migrants. The effects of forestry on migrating birds have received even less attention. To our knowledge, only one study examined relationships between silvicultural practices (hardwood removal and prescribed burning) and birds during spring and fall migration (Michael and Thornburgh 1971). Additional research on effects of forestry on permanent resident species and the use of managed forests as stopover sites for migrating birds is clearly needed.

Also of concern is that most (65 percent, n = 78) of our interpretations of forestry effects on bird populations are based upon measures of relative avian abundance, collected using point counts. Studies of species-habitat associations are known to be limited for numerous reasons (Wolff 1995), yet few researchers have critically questioned relationships between factors typically measured (i.e., relative abundance) and habitat quality (as might be better indicated by reproductive success, for example). Again, there are obvious reasons why abundance data are so commonly relied upon: point counts are simple and cost-efficient relative to alternative sampling methods. There are, however, some fundamental problems associated with use of abundance data as the only method to measure avian populations. Numerous studies, mostly on birds, have noted that density is not necessarily an accurate indicator of habitat quality (Krebs 1971, Van Horne 1983, Pulliam 1988, Robbins et al. 1989, Gibbs and Faaborg 1990, Blake 1991, Martin 1992, Vickery et al. 1992, Hagan et al. 1996, R. Sallabanks, unpubl. data). Inferences about actual quality of habitat can only be indirectly deduced from correlational and often poorly replicated bird surveys. Yet such studies are the norm.

Research should be directed more toward measuring avian fitness components and identifying critical structural characteristics of forests that influence nesting success, depredation rates, survivorship, and dispersal. Of course, others have recognized similar needs (e.g., Martin 1992), and studies that investigate population parameters have become more common in recent years (King et al. 1996, Machtans et al. 1996, Annand and Thompson 1997). Machtans et al. (1996) is the only published study to conduct sampling protocols related to songbird demographics (in this case, mist-netting) pre- and post-timber harvest. To our knowledge, there is yet to be a single published study of passerines that tests for treatment effects experimentally and measures direct changes in nest success in relation to timber harvest (i.e., experimental manipulations of forest structure where treatments and reference stands are randomly assigned and data are collected pre- and post-treatment).

Conclusions

One conclusion from our review is that forestry, in most cases, does not result in community-wide bird declines. On the contrary, we have found that managed forests support abundant, rich, diverse, and productive bird communities. There are obviously some species that favor old forest conditions and these conditions would clearly be altered by timber harvest. For example, Townsend's Warbler (Matsuoka et al. 1997, Sallabanks et al. 2002), Pileated Woodpecker (Bull and Holthausen 1993), and Brown Creeper (*Certhia americana*; Mariani and Manuwal 1990, Adams and Morrison 1993) are all species known to be associated with closed canopy forest and large-diameter trees, particularly snags. We do not dispute that such species are likely to be negatively impacted by certain forestry practices (e.g., clearcutting), at least at the stand level and over the short-term. On the other hand, there are just as many species that require forest habitat created by forestry, such as the Dark-eyed Junco, Dusky Flycatcher (*Empidonax oberholseri*), Orange-crowned Warbler (*Vermivora celata*), Chipping Sparrow, House Wren (*Troglodytes aedon*), and Mountain Bluebird (*Sialia currucoides*; Sallabanks et al. 2002). In order to maintain viable populations of all species on the landscape, a mix of all forest conditions, from clearcuts to old growth, is required. In reality, stand-level changes that cause species' declines may actually be required to maintain those species at the landscape scale (e.g., in order to maintain stand structures that are resistant to catastrophic disturbance). Several studies in our review suggested varying the amount of timber removed from stands during logging operations (e.g., Chadwick et al. 1986, Hagar et al. 1996). We agree, but also suggest applying this recommendation to broader spatial scales (e.g., Annand and Thompson 1997). If forest stands exist as a patchwork mosaic of different structural stages across broad landscapes, all but the most wide-ranging bird species should have adequate foraging and nesting sites. Perhaps one of the biggest questions left unanswered is "How much of each structural stage is required (and in what arrangement) on the landscape to successfully blend avian conservation with timber production?" This question is not easy to answer, but advanced modeling efforts combined with field tests of model predictions might be one approach for the future (e.g., Hansen et al. 1993, 1995a; Brooks 1997).

We also feel strongly that while having the landscape be comprised of a range of seral stages is important, maintaining and creating essential structural attributes is more critical. By leaving down logs, snags, patches or trees, old residual trees, and adequate shrub cover, managers can maintain species that may be dependent on structure rather than stand age or seral stage. In short, results from our review suggest that managing for structural features may be more important than managing for seral stage *per se*.

If management is to occur, our results indicate that uneven-aged methods will lead to fewer species' decreases compared with even-aged methods. Of course, this conclusion is largely driven by our unavoidable focus on short-term, stand-level results. At the stand level, uneven-aged management alters forest structure less dramatically than even-aged prescriptions. Thus, it is not surprising that uneven-aged management would have a less dramatic short-term, stand-level effect on bird communities. As we have documented here, response of bird communities differs little between the two harvesting systems when considered at larger spatial and temporal scales. Again, we see the need for variation on the landscape, both within and among forest stands. Following our review, there were no clear trends as to which specific forestry technique (e.g., single-tree selection or group selection) might be more conducive to maintaining high quality habitat for birds.

Avian research always will face trade-offs and compromises, often driven by logistical and financial constraints that prevent us from collecting the full complement of demographic data in an experimental, long-term framework. Such "Utopian" research will be challenging to develop and implement (Marzluff and Sallabanks 1998). Individual studies must have their own strengths that, when combined with those of others, will begin to complete the puzzle and fill information gaps. The past 40 years have produced some quality work that has greatly improved our understanding of effects of timber harvest on bird populations. To improve effectiveness, however, we urge that future research take some new directions. We encourage researchers to design and implement manipulative field studies wherever possible. To minimize confounding factors inherent to observational studies, we suggest increasing experimental rigor through: (1) inclusion of references (controls); (2) better replication in both space and time; (3) randomized selection of experimental units (replicates); (4) interspersion of experimental units across the study area (Hurlbert 1984); (5) gathering pre- and post-treatment data; and (6) lengthening study duration. With these recommendations in mind, and as long as the needs of forest managers are kept clearly in view, we believe that future research on the relationships between timber harvest and bird populations will continue to make both novel and significant contributions to this critical area of study. To achieve such studies, careful, insightful planning and involvement of forest managers from a project's inception will be required (Arnett and Sallabanks 1998). To increase power and experimental rigor of such studies, we also encourage researchers to coordinate and implement large-scale cooperative research programs involving multiple organizations and resources.

In conclusion, we echo our earlier comments that opportunities to enhance habitat for birds through forestry will vary from species to species. Management objectives must be prioritized based upon those bird species that are sensitive to forestry and showing sharp declines, as well as being compatible with ownership objectives. Continued research, especially that which incorporates information needs identified in this review, will help tell us which species these are and why they might be at risk. Attempts to improve habitat for all species by managing for maximum avian biodiversity have limited utility. What is needed are resourceful ways to integrate stand- and landscape-level features created by forestry with those required by birds for sustained avian population health and viability.

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Appendix 1. *Descriptive criteria for 116 studies of bird-forestry relationships included in our review. Space limitations prohibit the inclusion of actual results from each study. See footnotes for column definitions. Studies are listed in alphabetical order by primary author.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
1	W	MO	C	CC, SW, GS, ST	M	S	2	N	12	M	BB	RA, FT	Y	N	Y	Annand and Thompson (1997)
2	NW	OR	C	SL	U	S	2	Y	6	M	BB	RA	Y	N	N	Arnett et al. (2001)
3	W	UT	C	CC	E	S	1	N	1	M	BB	RA	N	N	N	Austin and Perry (1979)
4	E	KY	M	TA, CC	M	S	3	Y	4	M	BB	RA	Y	N	N	Baker and Lacki (1997)
5	S	AR	M	CC, ST	M	S	3	N	6	M	RN	FT	N	N	N	Barber et al. (2001)
6	SW	AZ	C	PC, CC	M	S	1	N	1	M	WB	RA	Y	Y	N	Blake (1982)
7	SW	AZ	C	CC, CT	M	S	3	N	1	M	BB	DN	N	N	N	Brawn and Balda (1988)
8	NW	OR	C	ST	U	S	1	N	1	M	BB	RA	N	N	N	Bull et al. (1995)
9	NE	MA	H	FC	U	S	2	N	16	M	BB	RA	Y	Y	Y	Chadwick et al. (1986)
10	NW	OR	C	GS, TA, CC	M	S	1	N	3	M	WB	RA	N	N	Y	Chambers and McComb (1997)
11	E	VA	H	CC	E	S	1	N	1	M	BB	RA	Y	N	Y	Conner and Adkisson (1975)
12	E	VA	M	CC	E	S	1	N	4	M	YB	RA	N	N	N	Conner et al. (1979)
13	NE	QC	C	CC	E	S	2	Y	20	M	BB	DN	N	N	N	Darveau et al. (1995)
14	NE	QC	C	CC	E	S	4	N	5	M	AN	FT	N	N	N	Darveau et al. (1997)
15	W	UT	H	CC	E	S	4	Y	1	M	BB	DN	N	N	N	Debyle (1981)
16	NE	NH	H	CC	E	E	3	N	6	M	BB	RA	Y	N	N	DeGraaf (1992)

Appendix 1. *Continued.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
17	NE	NH	H	CC, CT	M	S	1	N	3	M	AN	FT	Y	N	N	DeGraaf (1995)
18	NE	NH	H	CC	E	S	1	N	14	M	AN	FT	N	N	N	DeGraaf and Angelstam (1993)
19	NE	MA	H	ST	U	S	3	N	3	M	BB	RA	Y	N	N	DeGraaf et al. (1991b)
20	N	MI	H	CC	E	S	1	N	-	M	SS	RA	Y	N	Y	Dellasala and Rabe (1987)
21	NW	AK	C	CC, CT, GS	M	S	2	N	5	M	YB	RA	Y	Y	Y	Dellasala et al. (1996)
22	NE	ME	M	CC	E	S	4	N	10	M	BB	RA	Y	N	N	Derleth et al. (1989)
23	N	TX	H	SR	S	S	5	N	4	M	BB	RA	Y	N	Y	Dickson et al. (1983)
24	N	MI	H	SR	S	S	2	Y	3	M	BB	DN	Y	N	N	Dingledine and Haufler (1983)
25	E	WV	H	TA, CC	M	S	2	N	18	M	RN	FT	N	N	Y	Duguay et al. (1999)
26	NW	BC	C	CC	E	S	1	N	2	M	BB	RA	N	N	N	Eckert et al. (1992)
27	N	AB	C	CC	E	S	1	N	3	M	BB	RA	N	N	N	Farr (1992)
28	SW	AZ	C	OR	U	S	2	N	1	M	BB	DN	Y	Y	Y	Franzreb (1977)
29	SW	AZ	C	OR	U	S	2	N	1	M	BB	DN	Y	Y	N	Franzreb (1978)
30	SW	AZ	C	ST	U	S	2	N	1	M	BB	RA, DN	Y	N	N	Franzreb and Ohmart (1978)
31	N	NS	H	CC, CT	M	S	1	N	2	M	BB	DN	Y	N	N	Freedman et al. (1981)
32	NE	VT	H	CC	E	S	2	N	3	M	BB	RA	Y	N	N	Germaine et al. (1997)
33	SE	FL	M	CC	E	S	2	N	3	M	YB	RA	Y	N	N	Greenberg et al. (1995)
34	NE	ME	H	CC, CT	M	S, L	2	N	11	M	BB	RA	N	N	Y	Hagan et al. (1995)
35	NE	ME	H	CC	E	L	1	N	-	M	BB, SS	RA, FT	Y	N	Y	Hagan et al. (1996)

Appendix 1. *Continued.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
36	NE	ME	H	CC, CT	M	S, L	2	N	11	M	BB	RA	N	N	Y	Hagan et al. (1997)
37	W	CA	C	CC	E	S	3	N	7	M	BB	RA	N	N	N	Hagar (1960)
38	NW	OR	C	CT	U	S	2	N	8	M	YB	RA	Y	Y	Y	Hagar et al. (1996)
39	W	CO	C	CC, CT	M	S	2	N	1	M	YB	RA	Y	N	N	Hallock (1989–90)
40	SE	NC	H	CC	E	S	2	N	1	M	BB	DN	N	N	N	Horn (1984)
41	NE	ME	M	CC, ST	M	S	2	N	2	M	BB	DN	Y	Y	Y	Johnson and Brown (1990)
42	SE	NC	M	CC, CT	M	S	2	N	3	M	YB	RA	Y	Y	Y	Karriker (1996)
43	W	WY	C	CC	E	S	2	N	7	M	BB	RA	Y	N	N	Keller and Anderson (1992)
44	NW	AK	C	CC	E	S	1	N	2	M	BB	RA	Y	N	N	Kessler (1979)
45	W	CA	C	UR, SR	S	S	4	Y	2	M	BB	RA	Y	Y	N	Kilgore (1971)
46	NE	NH	H	CC	E	S	2	N	3	M	SS	FT	Y	N	Y	King et al. (1996)
47	NE	NH	H	CC	E	E	2	N	4	M	BB	DN	Y	N	N	King et al. (1997)
48	NE	NH	H	CC, GS	M	S, L	2	N	3	M	RN	FT	N	N	N	King et al. (2001)
49	SE	SC	M	CC	E	L	1	N	8	M	BB	RA	N	N	N	Lancia et al. (1996a)
50	SE	SC	M	CC	E	S	1	N	3	M	BB	RA	Y	N	N	Lancia et al. (1996b)
51	SE	SC	M	CC	E	L	2	Y	9	M	BB	RA	N	N	N	Lancia et al. (1997)
52	NE	VT	H	CC, ST	M	S	2	N	1	M	BB	RA, DN	Y	Y	N	Lent and Capen (1995)
53	N	AB	M	CC	E	S	3	Y	3	M	BB, MN	DN, FT	N	N	N	Machtans et al. (1996)
54	NW	OR	C	CT	U	S	3	N	4	M	BB	RA	Y	Y	Y	Mannan and Meslow (1984)
55	N	MN	H	CC	E	E	2	N	3	M	AN,	FT	N	N	Y	Manolis et al.

Appendix 1. *Continued.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
											RN					(2000)
56	E	VA	H	CC, ST	M	S	2	N	1	M	BB	RA	N	N	N	Maurer et al. (1981)
57	NW	MT	C	SW, GS, CC	M	S	6	N	2	M	CN	RA	Y	N	Y	McClelland (1980)
58	E	KY	M	CC	E	S	2	N	3	M	YB	RA	Y	N	N	McComb and Rumsey (1983)
59	E	KY	M	CT	U	S	4	Y	1	M	YB	RA	Y	N	N	McComb et al. (1989)
60	E	KY	M	SR	S	S	4	Y	1	M	YB	RA	Y	N	N	McPeek et al. (1987)
61	NW	ID	C	CT	U	S	4	Y	3	M	BB	DN	Y	N	N	Medin (1985)
62	NW	ID	C	ST	U	S	5	Y	2	M	BB	DN	N	N	N	Medin and Booth (1989)
63	S	TX	M	PC	U	S	2	N	1	M	YB	RA	N	N	N	Michael and Thorneburgh (1971)
64	SE	AL	H	CC	E	S	1	N	1	M	BB	RA	N	N	N	Mitchell and Lancia (1990)
65	SE	SC	H	CC	E	S	1	N	1	M	BB	RA	N	N	Y	Mitchell et al. (1991)
66	NW	OR	C	CC	E	S	1	N	2	M	BB	RA	Y	Y	N	Monthey (1983)
67	W	CA	M	CC, PC	M	S	4	N	1	M	BB	RA	Y	N	N	Morrison (1992)
68	N	AB	M	PC, CC	M	S	2	Y	3	M	BB	RA	Y	N	Y	Norton and Hannon (1997)
69	SE	FL	M	CC	E	S	6	Y	1	M	YB	DN	N	N	Y	O'Meara et al. (1985)
70	N	MI, MN	H	CC	E	S	8	Y	4	M	BB	DN	Y	N	N	Probst et al. (1992)
71	SE	FL	C	CC	E	S	1	N	3	M	YB	RA	Y	N	N	Repenning and Labisky (1985)
72	N	MI	C	CC	E	S	2	N	5	M	BB	RA	Y	Y	Y	Rogers et al. (1996)

Appendix 1. *Continued.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
73	SE	FL	M	CC, CT	M	S	4	Y	1	M	BB	RA	N	N	N	Rowse and Marion (1981)
74	NE	ME	M	CC	E	E	2	N	-	M	AN	FT	Y	N	N	Rudnicky and Hunter (1993)
75	NW	OR	C	CT	U	S	1	N	20	M	BB	RA	Y	Y	N	Sallabanks (1994)
76	NW	OR	C	CT	U	S	1	N	12	M	BB	RA	Y	Y	Y	Sallabanks (1995)
77	NW	ID	C	CT	U	S	3	Y	8	M	BB	RA	Y	Y	N	Sallabanks (1996)
78	NW	ID	C	CT	U	S	4	Y	8	M	BB	RA	N	N	N	Sallabanks (1997)
79	NW	OR	C	CT	U	S	3	N	12	M	BB	RA	Y	Y	Y	Sallabanks et al. (2002)
80	NW	ID	C	CC, CT	M	S	2	N	4	M	BB	RA	N	N	N	Sallabanks et al. (submitted ms)
81	S	AR	M	PC, CC	M	S, W	1	N	-	M	BB	RA	Y	N	N	Sams (1995)
82	N	AB	M	CC	E	S, L	3	Y	3	M	BB	RA	Y	N	N	Schmiegelow et al. (1997)
83	NW	OR	C	SR	S	S	2	N	3	M	CN	DN	Y	Y	Y	Schreiber and deCalesta (1992)
84	SW	AZ	C	SR	S	S	4	Y	1	M	BB	DN	Y	N	Y	Scott (1979)
85	W	CO	H	CC	E	S	1	N	4	M	BB	RA	N	N	N	Scott and Crouch (1987)
86	W	CO	H	CC	E	S	1	N	10	M	BB	RA	N	N	N	Scott and Crouch (1988)
87	SW	AZ	C	CC	E	S	4	Y	2	M	BB	DN	N	N	N	Scott et al. (1982)
88	SW	AZ	C	ST, GS, CC	M	S	4	Y	1	M	BB	RA	Y	N	Y	Scott and Gottfried (1983)
89	SW	AZ	C	SR	S	S	4	Y	1	M	CN	DN	Y	N	Y	Scott and Oldemeyer (1983)

Appendix 1. *Continued.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
90	N	WI	H	CC	E	S	2	N	1	M	BB	RA	Y	N	N	Steffen (1985)
91	S	TX	M	CC	E	E	1	N	4	M	BB	RA	Y	N	Y	Strelke and Dickson (1980)
92	NE	PA	H	CT, SR	U	S	1	N	2	M	BB	RA	Y	Y	Y	Stribling et al. (1990)
93	SW	AZ	C	CT, SW	U	S	2	N	1	M	BB	DN	Y	N	Y	Szaro and Balda (1979)
94	SW	AZ	C	CC, PC	M	S	3	N	1	M	BB	DN	Y	Y	N	Szaro and Balda (1986)
95	S	AR	M	PC, CC	U	S, W	2	N	1	M	BB	RA	N	N	N	Tappe (1996)
96	NE	VT	H	CC, PC	M	S	2	N	6	M	BB	RA	Y		Y	Thompson and Capen (1988)
97	MW	MO	H	CC	E	S	4	Y	3	M	BB	RA	Y	N	N	Thompson and Fritzell (1990)
98	MW	MO	M	CC	E	S	2	N	9	M	BB	DN	N	N	N	Thompson et al. (1992)
99	NE	ME	C	CC	E	S	1	N	3	M	BB	DN	Y	Y	N	Titterington et al. (1979)
100	NW	MT	C	CC, PC	M	S	2	N	4	M	BB	RA	Y	N	Y	Tobalske et al. (1991)
101	E	KY	M	CC, PC	M	S	2	Y	2	M	BB	RA	N	N	Y	Triquet et al. (1990)
102	NE	NY	H	CC, PC	M	S	10	N	1	M	BB	RA	N	N	N	Webb et al. (1977)
103	N	ON	M	ST	U	S	1	N	-	M	BB	DN	N	N	N	Welsh (1987)
104	NE	NH	H	CC	E	S	2	N	3	M	BB	RA	Y	N	N	Welsh and Healy (1993)
105	NE	MA	H	ST, SR	U	S	2	N	4	M	CN	RA	Y	N	Y	Welsh et al. (1992)
106	NW	BC	C	CC	E	S	1	N	4	M	BB	RA	N	N	N	Wetmore et al. (1985)
107	E	MD	H	ST	U	S	2	N	1	M	BB	RA	N	N	N	Whitcomb et al. (1977)
108	SE	NC	H	CT	U	S	1	N	6	M	BB	RA	Y	Y	N	Wilson and Watts (1988)
109	NE	PA	M	CC	E	S	3	N	3	M	YB	RA	Y	Y	N	Yahner (1986)

Appendix 1. *Continued.*

No.	Reg[1]	State	Hab[2]	Pres[3]	Cat[4]	Scl[5]	Dur[6]	BvA[7]	Rep[8]	Type[9]	Birds[10]	Data[11]	Veg[12]	B-H[13]	Mgt[14]	Reference
110	NE	PA	M	CC	E	S	4	N	3	M	YB	RA	Y	Y	N	Yahner (1987a)
111	NE	PA	M	CC	E	S	3	N	5	M	RN	FT	N	N	N	Yahner (1991)
112	NE	PA	M	CC	E	S	2	N	10	M	YB	RA	N	N	N	Yahner (1993)
113	NE	PA	M	CC	E	S	1	N	10	M	AN	FT	N	N	N	Yahner and Mahan (1996a)
114	NE	PA	M	CC	E	S	1	N	10	M	AN	FT	N	N	N	Yahner and Scott (1988)
115	NE	PA	M	CC	E	E	1	N	15	M	AN	FT	Y	N	N	Yahner et al. (1989)
116	NW	WA	C	CC, PC, SR	M	S	2	N	2	M	CN	DN	Y	Y	Y	Zarnowitz and Manuwal (1985)

[1] Reg = Geographical region of study (E = East, MW = Midwest, N = North, NE = Northeast, NW = Northwest, S = South, SE = Southeast, SW = Southwest, W = West)
[2] Hab = Forest habitat (C = Coniferous, H = Hardwoods, M = Mixed);
[3] Pres = Silvicultural prescription studied (CC = Clearcut, CT = Commercial thin, FC = Fuelwood cutting, GS = Group selection, OR = Overstory removal, PC = Partial cut, SL = Salvage logging, SR = Snag removal/retention, ST = Single-tree selection, SW = Shelterwood, TA = Two-age cut, UR = Understory removal);
[4] Cat = Prescription category (E = Even-aged, M = Mix of even- and uneven-aged, U = Uneven-aged);
[5] Scl = Spatial scale of study (E = Edge effects study, L = Landscape-level, S = Stand-level, W = Watershed-level);
[6] Dur = Study duration (number of field seasons that data were collected);
[7] BvA = Before vs. after treatment data were collected and compared (Y = Yes, N = No);
[8] Rep = Degree of replication (mean no. replicate stands or plots studied per treatment);
[9] Type = Type of study (M = Mensurative or correlational, E = Manipulative experiment);
[10] Birds = Bird species or nest type studied (AN = Artificial nests, BB = Breeding birds, CN = Cavity nesters, RN = Real nests, SS = Single species, WB = Wintering birds, YB = Year-round birds);
[11] Data = Data type collected (DN = Density estimates, FT = Fitness parameters [e.g., nest success, productivity], RA = Relative abundance);
[12] Veg = Vegetation or habitat data collected (Y = Yes, N = No);
[13] B-H = Bird-habitat relationships examined and identified (Y = Yes, N = No);
[14] Mgt = Management recommendations made (Y = Yes, N = No).