Effects of Timber Harvesting and Plantation Development on Cavity-nesting Birds in New Brunswick

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We studied the abundance of cavity-nesting birds in forestry-related habitats in a region of Acadian forest in New Brunswick. We examined five reference stands of natural forest, a chronosequence of conifer plantations up to 19 years old (the oldest in the study area), two selectively harvested stands, and a 30-year-old naturally regenerated clear-cut. The species richness and abundance of cavity-nesting birds were higher in reference forest (average 10.0 species per stand; 5.3 territories per 10 ha) than in plantations (2.3/stand; 1.0/10 ha), selectively harvested stands (7.0/stand; 3.8/10 ha), or the naturally regenerated clear-cut (5.0/stand; 2.5/10 ha). A cluster analysis segregated the "community" of cavity-nesting birds of natural forest from those of other treatments. Of the various harvested stands and plantations, five with a relatively large number of residual snags clustered similarly in the cluster analysis, while those with no or very few snags also clustered together. We used arrays of nest boxes (12 per stand) to examine whether the availability of cavities was limiting the use of habitats otherwise suitable for foraging by cavity-dependent species. Nest-box use for nesting and roosting was much higher in the seven plantations examined (average 4.0/10 ha for nesting and 2.9/10 ha for roosting) than in three reference stands (each 0.3/10 ha), suggesting that the plantations were deficient in this critical-habitat element. Our results suggest that certain mitigations, such as leaving residual snags and living cavity-trees, would help maintain populations of some cavity-dependent birds in clear-cuts and plantations. However, some cavity-dependent species might not be accommodated by these mitigations and are potentially at risk in intensively managed areas, unless landscape-scale management plans ensure the survival of sufficient areas of older mixed-wood forest.

Key Words: Acadian forest, cavity-nesting birds, conifer plantations, critical habitat, forestry, management recommendations, nest boxes, New Brunswick.

The effects of forestry on biodiversity range over a wide continuum, depending largely on the intensity of harvesting and subsequent management (Hunter 1990; Freedman et al. 1994; Angelstam and Milkusinski 1994; Freedman 1995; Hagan et al. 1997; Niemi et al. 1998; Imbeau et al. 2001; McRae et al. 2001; Kimmins 2003). For instance, clear-cutting followed by intensive management to develop an even-aged monocultural plantation has relatively extreme effects, while the effects associated with selective-harvesting and natural regeneration are much smaller. In boreal Europe, for example, natural pine (*Pinus sylvestris*) forest has been converted extensively into commercially preferred, short-rotation conifer plantations (Esseen et al. 1997), resulting in large declines of birds dependent on older natural forest (Virkkala 1991). Similar changes are occurring in temperate- and boreal-forest regions of Canada, where older mixed-species forest is being converted extensively into conifer plantations (Niemi et al. 1998; Imbeau et al. 2001; McRae et al. 2001).

Cavity-dependent birds in temperate and boreal forest are generally most abundant and species-rich in older, uneven-aged, mixed-species stands (Hunter 1990; Schreiber and Decalesta 1992; Newton 1994; Freedman et al. 1996; Hobson and Schieck 1999; Schieck and Hobson 2000). Intensive forestry practices generally decrease the richness and abundance of cavity-dependent birds by causing the following habitat changes to occur (Niemi et al. 1998; Hobson and Bayne 2000; Flemming and Freedman 1998; Imbeau et al. 2001; Kirk and Machtans 2004; McRae et al. 2001):

- the conversion of natural forest having complex biological and physical structure (i.e., multi-species stand composition and intricate spectra of age and size) into silvicultural plantations dominated by a monospecific cohort of similar-sized and -aged trees
- the reduction in quantity of cavity trees, dead snags, and coarse-woody debris by intensive management practices (in Canada and elsewhere snag felling may even be required under health and safety regulations; e.g., Naylor et al. 1999)
- the truncation of stand age-at-maturity by short-rotation management (typically 40-60 years), which precludes the regeneration of large cavity-trees and coarse-woody debris

Moreover, at the level of landscape, forestry typically decreases the average age and complexity of habitat "patches," while isolating remnants of older natural forest (Hunter 1990; Freedman et al. 1994; Hagan et al. 1997; McRae et al. 2001). Landscape-scale forest management must accommodate species with extensive and specialized habitat needs, including some cavity-nesting birds dependent on older forest (Renken and Wiggers 1989, 1993; Bull and Holthausen 1993; Freedman et al. 1996; Bonar 2000).

Because of the specialized need of cavity-users for critical habitat, they are often considered indicators of the ecological sustainability of forest management (Angelstam and Mikusinski 1997). It is particularly important to maintain the habitat used by "keystone" primary excavators, such as older heart-rotten trees and snags, because a diverse group of secondary users depends on the cavities they create (Freedman et al. 1996; Martin and Eadie 1999). The Pileated Woodpecker (*Dryocopus pileatus*) is one example of a keystone excavator whose abandoned cavities are used by other species for nesting or roosting (Bull and Jackson 1995; Bonar 2000).

The effects of forestry on cavity-users are relatively wel known for forest types of the eastern and northwestern United States (Raphael and White 1984; DeGraaf and Shigo 1985; Zarnowitz and Manuwal 1985; Renken and Wiggers 1989; Connor et al. 1994). However, much less information is available on which to base management decisions in the north-temperate and boreal regions of eastern Canada. This deficiency is important because habitat needs of cavity-nesters vary geographically and are likely to be different in boreal and Acadian forest than in other regions and biomes (Parker et al. 1999). In recognition of this dearth of information, studies were initiated in the mid-1990s of cavity-nesting birds in eastern Canada, with the intent of informing management guidelines to conserve their populations (Doyon et al. 1999; Naylor et al. 1999; Bonar 2000; Flemming et al. 2000). This advice is greatly needed, because of the increasing areas of natural forest that are being intensively managed for timber production in eastern Canada.

Within this context, our study examines effects of forestry on cavity-dependent birds in a region of Acadian forest in southern New Brunswick. We assessed the degree to which cavity-nesting birds use conifer plantations and less-intensively managed stands, compared with natural forest. This was done by conducting breeding surveys of these habitats and by comparing occupancy of nest boxes as an indicator of limitation by natural cavities.

Study Area

The study area is in southeastern New Brunswick, Canada. It is located in the Atlantic Maritime Ecozone (Ecological Stratification Working Group 1995), within the Fundy Plateau Ecodistrict of the Acadian Forest Region (Loucks 1962; Rowe 1972). The climate is humid temperate and the natural forest is dominated by mixed-species stands of Red Spruce (*Picea rubens*), White Spruce (*P. glauca*), Balsam Fir (*Abies balsamea*), Sugar Maple (*Acer saccharum*), Red Maple (*A. rubrum*), Yellow Birch (*Betula alleghaniensis*), White Birch (*B. papyrifera*), and Mountain Birch (*B. cordifolia*). Extensive natural disturbances, including irruptions of native Spruce Budworm (*Choristoneura fumiferana*), have affected the natural forest, which tends to have a mixed-species canopy with gap-phase regenerating patches. Superimposed on the natural disturbance regime is a complex of anthropogenic influences. This began with the selective harvesting of large trees for lumber and ship-building, followed by extensive deforestation for agricultural development, then abandonment of most poorer-quality farmland beginning in the 1920s, and more recently the widespread establishment of conifer plantations.

Our study area is within the Greater Fundy Ecosystem (GFE), a region consisting of Fundy National Park and its surrounding area. The GFE was defined to study ecological consequences of the insularization of Fundy National Park, a 204 km^2 protected area embedded within a landscape whose matrix is being transformed by the conversion of natural forest into conifer plantations (Woodley et al. 1993, 1998; Freedman et al. 1994). The GFE itself is within the Fundy Model Forest (FMF), one of ten "model forests" established to demonstrate "sustainable forestry" in Canada. One declared indicator of sustainability in the FMF is that, at the landscape level, native biodiversity must not be compromised by forest management (Parker et al. 1999).

Methods

Stand selection

We selected 18 stands for study (see Table 1), including representative natural (or "reference") forest and habitats resulting from various intensities of management, including:

- five reference stands of unmanaged mature forest, including three mixed woods (dominated by Red Spruce (*Picea rubens*), Balsam Fir (*Abies balsamea*), and White Birch (*B. papyrifera*), and Mountain Birch (*B. cordifolia*) and two softwood dominated by Red Spruce;
- ten stands that had been clear-cut and then intensively managed to develop conifer plantations ranging from 5 to 19 years in age (the oldest available in the study area); eight were planted with Black Spruce (*Picea mariana*), one with Jack Pine (*Pinus banksiana*), and one with Norway Spruce (*Picea abies*);
- two selectively harvested stands (1-year-old and 12-years-old);
- one 30-year-old naturally regenerated clear-cut.

TABLE 1. General habitat characteristics of stands surveyed for cavity-nesting birds.

Site	Survey Year	Area (ha)	Stand description
Reference mixedwood forest			
Ra	1994	10	mature/mixedwood forest; Red Spruce, Balsam Fir, White Birch
Rb	1995	20	mature/mixedwood forest; Red Spruce, Balsam Fir, White Birch
Rc	1994	10	mature/mixedwood forest; Red Spruce, Balsam Fir, White Birch
Rd	1994	10	mature/Red Spruce-dominated forest
Re	1995	20	mature/Red Spruce-dominated forest
Plantations			
P5a	1994	10	5-year-old Black Spruce plantation
P5b	1994	10	5-year-old Norway Spruce plantation
P7	1995	20	7-year-old Black Spruce plantation with residual snags
P8	1994	10	8-year-old Black Spruce plantation
P9a	1994	10	9-year-old Black Spruce plantation
P9b	1994	10	9-year-old Jack Pine plantation
P15	1995	8	15-year-old Black Spruce plantation with residual snags
P17	1994	10	17-year-old Black Spruce plantation
P18	1995	10	18-year-old Black Spruce plantation
P19	1994	10	19-year-old Black Spruce plantation
Selectively harvested stands			
S12	1995	20	12-year-old selection harvested stand
S1	1995	20	1-year-old selection harvested stand
Naturally regenerated clear-cut			
NR30	1995	20	30-year-old naturally regenerated clear-cut with residual snags

Note that selected study stands were not always paired because of the lack of availability of suitable stands that were given the same management. The study plots affected by forestry were essentially operational stands embedded in a dissimilar habitat matrix generally of mixed-wood forests, and they were surveyed in their entirety. The reference plots were of a size and shape comparable to forestry-affected plots. The study stands were no more than 20 km from each other. Fieldwork was done during 1994 and 1995.

Habitat description

Trees (≥5 cm diameter at breast height (DBH) and >1.5 m tall) and snags (standing dead trees) were sampled in twelve quadrats (20 m × 20 m) arranged as a grid across the study plot. However, in plantations 15 years and older, smaller quadrats (10 m × 10 m) were used because of the uniform structure of tree-sized vegetation. Shrubs (<5 cm DBH) were measured for diameter at 25 cm in two 5 m × 5 m sub-quadrats in opposite corners of each tree-quadrat. Length and diameter of coarse-woody debris (CWD; >5 cm diameter) were also measured in tree-quadrats. The field data were used to calculate the average DBH and basal area by species, including snags, and the volume of CWD.

The cover of species of ground vegetation was determined in 30 randomly located 1 m^2 quadrats per site. The cover of overhead canopy was estimated as the percentage area obscured by foliage when sighting upward through a 4.2-cm diameter cylinder. Here we present summary information; detailed data on woody habitat are in Flemming and Freedman (1998) and on ground vegetation are in Veinotte et al. (2004).

Abundance of birds

Cavity-nesting birds were surveyed by modified spot-mapping to identify territories (Bibby et al. 1999). Habitat use was designated as "nesting territory" if we found evidence of a nest, and as "present" if a nest site could not be located. The surveys were conducted in plots with areas of 8 to 20 ha (Table 1). Ten stands were surveyed in 1994 and eight in 1995, and each was examined seven times from early June through to early July. The locations of calling or singing male birds were mapped in the study plots and also in adjacent habitat, and territorial boundaries were estimated using standard spot-mapping procedures (Bibby et al. 1999). Where possible, we recorded the sex, age (adult/juvenile), and relevant activity (nesting, feeding young, foraging, drumming, singing, calling) of individuals. This information contributed to the assignment of breeding territories.

Nest-box survey

To indicate whether cavities were a limiting factor for dependent species, we installed arrays of 12 nest boxes in each of seven plantations and three reference stands. The nest boxes were made of sections of White Cedar (*Thuja occidentalis*) with natural heart rot and were divided into three sizes: small (3.5-cm diameter entrance hole; ca. 6.5-cm internal width by 16 cm height), medium (6-cm hole, 11 × 34 cm), and large (9-cm hole; 15 × 48 cm). Because the site location and orientation of the entrance hole can affect occupancy (Rendell and Robertson 1994), these factors were standardized. Each nest box was mounted on an aspen pole supported by three steel cables fixed to rebar pegs, and was placed at a predetermined height (small cavities at 2.5 m, medium at 3 m, and large at 5 m) with the entrance hole facing south. A total of 12 nest boxes was placed in each stand; two of each of size were positioned at 30 m and again at 100 m from a stand edge. The nest boxes were surveyed seven times during each of the 1994 and 1995 breeding seasons, and once late in the summer. We recorded the numbers of eggs, hatchlings, and fledglings of any species occupying the boxes, as well as roosting birds and non-avian species.

Data analysis

Because the study plots were unique habitats in terms of location, site and habitat attributes, and disturbance history, they were not treated as true statistical "replicates" (Hurlbert 1984; Heffner et al. 1996). Moreover, many of our data did not meet assumptions of normality or homegeneity of variance. Consequently, we restricted our analyses to simple comparisons among classes of habitat types. Relationships among stands were examined using multivariate analyses, with data input being matrices of species abundance by site (Kovach 1995). A cluster analysis was used to identify groupings of stands (or "communities"), using an unweighted pair-group procedure with arithmetic averages (UPGMA; Sokal and Rohlf 1995). Chi-square contingency tests were used to test for differences in occupancy rate of nest boxes between (a) unmanaged and managed stands and (b) boxes located at 30 m or 100 m from a forest edge.

Results and Discussion

Habitat

The stands of natural (reference) forest had a large basal area (an indicator of biomass) of trees compared with the other habitats studied (Table 2). Although a high tree density occurred in older plantations and the naturally regenerated site, these were smaller trees than in natural forest. The species composition of the natural forest was mixed, whereas the plantations are more strongly dominated by the planted conifer species. The natural forest also had relatively abundant snags. Of the various managed stands, only the 7-year-old and 15-year-old plantations (P7 and P15, respectively) had many snags, because the pre-harvest snags had not all been removed or felled during the clear-cut, and a subsequent herbicide treatment killed surviving hardwood trees. The 30-year-old naturally regenerated clear-cut also had abundant snags, as did the 12-year-old selectively harvested site. Coarse-woody debris was abundant in the stands of reference forest, where it originated as natural deadfall. Coarse-woody debris was also abundant in the plantations and selectively harvested stands, where it mostly originated as logging slash and, in older plantations, trees cut and left during a non-commercial thin. Similar but more detailed observations have been made by other studies of natural forest and plantations in our study area (Flemming and Freedman 1998).

TABLE 2. Summary of key habitat data (presented as mean area).

	Reference Stands					Plantations										Selection		Nat'l Regen
	Ra	Rb	Rc	Rd	Re	P5a	P5b	P7	P8	P9a	P9b	P15	P17	P18	P19	S1	S12	NR30
Tree Basal Area (m^2/ha)																		
Conifers	18.3	18.3	19.0	30.3	30.2	0.0	0.0	0.0	0.0	0.2	3.2	8.9	10.8	26.3	15.0	0.0	8.7	20.2
Hardwoods	10.9	10.9	6.4	10.7	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.1	0.0	7.9	2.7
Snags	6.1	3.6	11.4	5.1	5.0	0.0	0.0	3.8	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.7	2.0
Tree Density (10^3/ha)																		
Conifers	0.6	0.6	1.0	0.9	0.9	0.0	0.0	0.0	0.0	0.1	0.9	2.4	3.0	4.7	2.3	0.0	0.5	2.6
Hardwoods	0.5	0.5	0.2	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0.4
Snags	0.2	0.2	0.7	0.5	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2
Shrub Basal Area (m^2/ha)	0.2	0.2	1.5	1.2	1.1	2.6	2.1	1.4	2.2	4.8	5.6	3.2	3.3	3.3	4.2	0.7	2.9	2.4
Coarse-Woody Debris (m^3/ha)	23.0	23.2	45.4	22.6	22.9	83.7	47.8	30.5	21.3	31.1	16.2	12.3	11.2	40.1	20.1	40.2	15.8	7.1

TABLE 3. Abundance and species richness of cavity-nesting birds. Data are standardized as territories per 10 ha; + indicates <0.5 territory; P indicates the species was present on the site. REFERENCE refers to natural, mature, mixed-species forest; PLANTATION refers to intensively managed conifer plantations; SELECTION refers to sites that were selectively harvested; NAT REGEN refers to a 30-year-old naturally regenerated clear-cut. Numbers associated with site name-codes indicated the number of years since the original forest was harvested.

Species	Reference					Plantation										Selection		Nat'l Regen
	Ra	Rb	Rc	Rd	Re	P5a	P5b	P7	P8	P9a	P9b	P15	P17	P18	P19	S1	S12	NR30
Kestrel								0.5	1			+						
Barred Owl					P													
Saw-whet Owl		+																
Yellow-bellied Sapsucker	P	+	P	P												+	0.5	
Downy Woodpecker	P	P	1	1	0.5											0.5	P	P
Hairy Woodpecker	P	P		P				P								+	P	
Black-backed Woodpecker	P		P															
Northern Flicker	P	P			P	P	1	0.5		1	P	1.0	P	P	P	+		
Pileated Woodpecker	P	P	P	P	+													
Tree Swallow							1											
Black-capped Chickadee	2	2	2	P	1								P		P	2.0	1.5	P
Boreal Chickadee	1	1	1	P	1.5							3.0	P		1	P		1.5
Red-breasted Nuthatch	1	2	P	P	1.0							P			P	1.5	0.5	1.0
White-breasted Nuthatch				P														
Brown Creeper	P	0.8	P	1	0.5			+							P	1.0		
Winter Wren	3	1.5	P	1	0.5												P	+
Total Territories	7.0	7.3	4.0	3.0	5.0	0.0	2.0	1.0	1.0	1.0	0.0	4.0	0.0	0.0	1.0	5.0	2.5	2.5
Species Richness	11	11	9	10	9	1	2	4	1	1	1	4	3	1	5	8	6	5

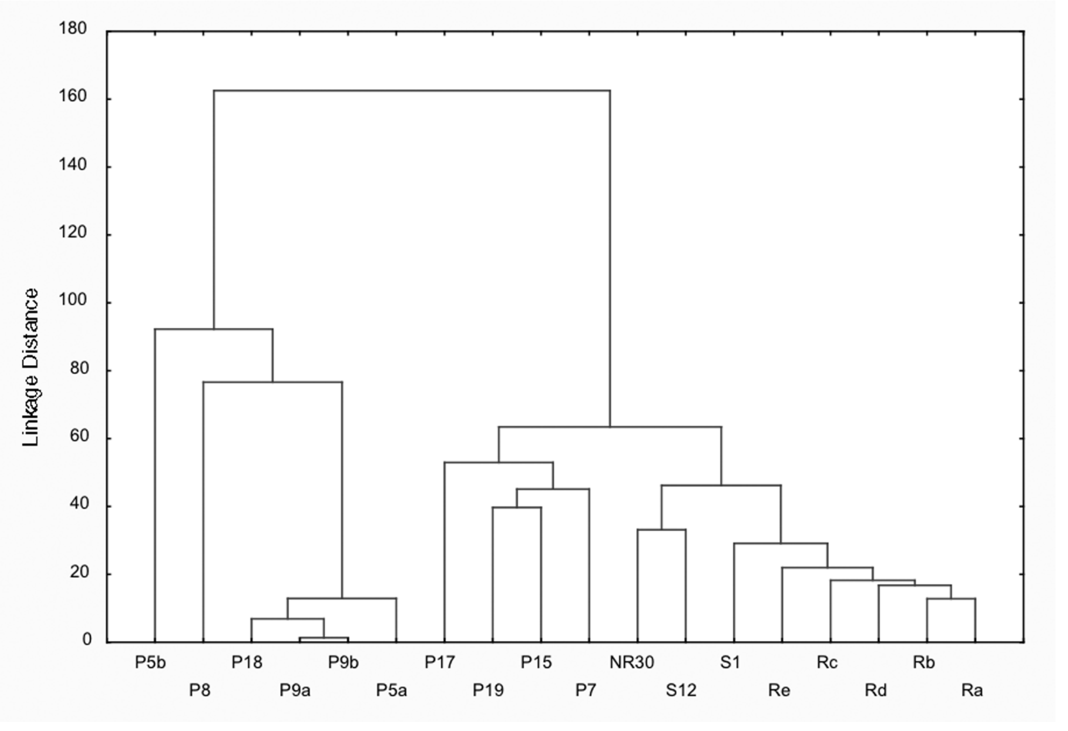

FIGURE 1. Cluster analysis of stands based on their species and abundances of cavity-nesting birds. See Table 1 for explanation of site codes.

The abundance and cover of shrubs and ground vegetation were highly variable among stands (Table 3). In general, these vegetation elements were more abundant in the plantations and other harvested stands, which were in younger stages of secondary succession than the more mature natural forest. Similar, but more detailed observations of forest and plantations in our study area have been made by Veinotte et al. (2004).

Cavity-nesting Birds

A total of 16 species of cavity-nesting birds was observed (Table 3). The most abundant species were the Black-capped Chickadee (24% of the territories; see Appendix 1 for avian binomials), Boreal Chickadee (23%), Red-breasted Nuthatch (16%), and Winter Wren (14%). The species richness was higher in the natural forest (average of 10.0 species per stand; total of 14 species present in the habitat type) than in plantations (2.3/stand; 8 species present), selectively harvested stands (7.0/stand; 9 species present), or the naturally regenerated clear-cut (5.0/stand). Abundance was also higher in the reference forest (average 5.3 territories/10 ha) than in plantations (1.0/10 ha), selectively harvested stands (3.8/10 ha) or the naturally regenerated clear-cut (2.5/10 ha). Among the ten plantations studied, the highest density of cavity-nesting birds was in P15 (4.0 territories/10 ha), which also had a relatively large number of snags (2.1 m^2/ha compared with an average of 0.4 m^2/ha among the other nine plantations).

A cluster analysis segregated the "community" of cavity-nesting birds of the natural forest from those of the other treatments (Figure 1). In the cluster analysis, the five reference stands were arranged together on the right-hand side. The selectively harvested stands (S1 and S12) and naturally regenerated stand (NR30) had relatively abundant cavity-nesting birds and clus-

TABLE 4. Cavity-using species encountered in this study.

American Kestrel	*Falco sparverius*
Barred Owl	*Strix varia*
Northern Saw-whet Owl	*Aegolius acadicus*
Northern Flicker	*Colaptes auratus*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Downy Woodpecker	*Picoides pubescens*
Hairy Woodpecker	*Picoides villosus*
Black-backed Woodpecker	*Picoides arcticus*
Pileated Woodpecker	*Dryocopus pileatus*
Tree Swallow	*Tachycineta bicolor*
Black-capped Chickadee	*Poecile atricapillas*
Boreal Chickadee	*Poecile hudsonicas*
Brown Creeper	*Certhia americana*
White-breasted Nuthatch	*Sitta carolinensis*
Red-breasted Nuthatch	*Sitta canadensis*
Wood Duck	*Aix sponsa*
Winter Wren	*Troglodytes troglodytes*

tered close to the reference stands. Of the plantations, those with relatively abundant and species-rich cavity-nesting birds clustered together (i.e., P7, P15, P19, and P17), while the most depauperate ones formed another cluster (i.e., P5b, P8, P9a, P9b, P5a).

The observation that cavity-nesters are more abundant in mature mixedwood forest than in harvested stands or plantations is consistent with research elsewhere, although the specifics vary depending on the forest region and species of birds present (e.g., Raphael and White 1984; DeGraaf and Shigo 1985; Zarnowitz and Manuwal 1985; Hansen et al. 1995; Kirk and Naylor 1995; Niemi et al. 1998; Hobson and Bayne 2000).

Of the 16 species of cavity-nesting birds recorded during our study, eight were not recorded in any of the plantations: Saw-whet Owl, Barred Owl, Yellow-bellied Sapsucker, Downy Woodpecker, Black-backed Woodpecker, Pileated Woodpecker, White-breasted Nuthatch and Winter Wren. One species, the Tree-Swallow, was only recorded as breeding in plantations in which nest boxes were present.

Nest-box Occupancy

Nest boxes were used by five species for nesting and by four for roosting (Table 4). Tree Swallow accounted for 41% of the nests, American Kestrel 31%, and Boreal Chickadee 17%. The most frequently roosting species were Tree Swallow (48%) and Northern Flicker (33%). The use of nest-boxes for nesting was much greater in plantations (average 4.0/10 ha) than in the natural forest (0.3/10 ha), and similarly for roosting (average 2.9/10 ha in plantations and 0.3/10 ha in reference stands). Overall, 33% of the nest boxes in plantations were used for nesting or roosting (28 of 84 boxes with nests), compared with only 3% in natural forest (1 of 36 boxes with nests). These observations support the notion that suitable cavities are a limiting factor in plantations in the study area, compared with the natural forest. The plantations we studied appear to provide suitable habitat for foraging and other purposes, but can only be used for nesting and roosting by cavity-dependent birds if their need for cavities is met. There were no recorded cases of a failed nest in the nest boxes.

Of the 28 nest boxes used for nesting in plantations, 7.5% were located 30 m from an intact forest edge and 15.8% were 100 m from such an edge (marginally significant difference; $\chi^2 = 3.78$, 1 df; $>0.05\ P < 0.1$). The apparent reluctance to use nest-boxes located closer to a habitat edge may be associated with a greater risk of predation (Paton 1994; Derochers and Hannon 1997).

Implications for Management

It appears that conifer plantations in our study region can recover bird populations rather quickly after establishment, but the species composition is different from that of natural forest, and cavity-dependent species are present in low abundance (Freedman et al. 1994; Freedman and Johnson 1999; Johnson and Freedman 2002). Moreover, observations and models of stand development suggest that intensively managed plantations are depauperate in snags, cavity-trees, and coarse-woody debris and are likely to remain so over subsequent rotations because the harvesting removes all large-dimension tree biomass (Flemming and Freedman 1998). These changes do not augur well for cavity-dependent species in stands and landscapes extensively converted into forestry plantations.

Clearly, the extensive conversion of mixedwood Acadian forest into conifer plantations will result in a decline in the abundance and species richness of cavity-dependent birds at the scales of both stand and landscape. Certain site mitigations might help some species, particularly the retention of some snags and large living trees within plantations, or much less preferably, the provision of nest boxes to provide local nesting and roosting habitat (Welsh and Capen 1992; Newton

TABLE 5. Use of nest boxes in plantations and reference forest during two study years. Each site had an array of 12 nest boxes, each made of a section of a hollow log of White Cedar. All plots were 10 ha in area. Note some stands from Table 3 had no nest boxes installed, so the number of stands differs between Table 3 and 4.

Species	Reference			Plantation						
	Ra	Rc	Rd	P5a	P5b	P8	P9a	P9b	P17	P18
Nesting										
Wood Duck				1						
American Kestrel				2	2	2	2	1		
Northern Flicker					1	1				
Tree Swallow				2	3	3	3		1	
Boreal Chickadee		1							2	2
Total nests	0	1	0	5	6	6	5	1	3	2
Roosting										
American Kestrel					1		2			
Pileated Woodpecker			1							
Northern Flicker					1		3	2	1	
Tree Swallow					2	5	3			
Total roosting	0	0	1	0	4	5	8	2	1	0

1994; Flemming et al. 2000). It is likely, however, that these site mitigations will not be sufficient to maintain some cavity-dependent species, particularly those with large home ranges that encompass a mosaic of habitat patches, such as Pileated Woodpecker (Bonar 2000; Flemming et al. 2000). These species will require large protected areas of unmanaged forest to function as population centres.

Without sympathetic management of this sort, it is likely that the population viability of some cavity-dependent birds in regions extensively managed for forestry will become compromised. Some jurisdictions have established guidelines to help these species — in New Brunswick, for example, timber companies operating on Crown Land are to required to retain at least 10% of conifer-dominated forest in mature or older successional stages, in patches of 500 or more ha (Sullivan 1996). However, these requirements may not be adequate to maintain critical habitat for all species of cavity-nesting birds, particularly keystone primary excavators (Flemming et al. 2000). It is essential that these conservation guidelines be monitored to ensure they achieve their intended ecological purpose, including the maintenance of viable populations of all cavity-dependent species. In the meantime, a precautionary approach to ecologically sustainable forestry would require that additional large areas of natural forest be set aside from intensive economic use, as parks or other kinds of protected areas.

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