The Effect of Forest Roads on the Reproductive Success of Forest-Dwelling Passerine Birds

David I. King and Richard M. DeGraaf

ABSTRACT. Recent studies indicate that forest roads may affect the distribution of forest-dwelling birds. However, previous studies have not demonstrated any significant effects of forest roads on avian productivity. We studied the effect of maintained and unmaintained forest roads on (1) forest bird nest survival, (2) reproductive parameters of ovenbirds (*Seiurus aurocapillus*) potentially associated with food abundance, and (3) habitat and microclimate at six sites on the White Mountain National Forest, New Hampshire, during two breeding seasons. Nest survival did not differ between areas near (0–150 m) and far (>150 m) from maintained forest roads, and was marginally ($P = 0.08$) higher in areas near (0–150 m) unmaintained roads. When the 0–150 m distance class was subdivided, however, nest survival was significantly higher within 0–75 m of maintained roads than >75–150 m away. Ovenbird nest initiation dates, clutch size, and fledging success did not differ between areas near (0–150 m) and far (>150 m) from maintained and unmaintained forest roads, and this result did not change when the distance class 0–150 m from roads was subdivided. There were no relationships between habitat or microclimate and distance from maintained roads. We conclude that small, unsurfaced forest roads at low road density do not result in decreases in forest passerine bird productivity in extensively forested areas in New England. For. Sci. 48(2):391–396.

Key Words: Edges, habitat, microclimate, nest success, *Seiurus aurocapillus*.

The creation of forest roads has come under increasing scrutiny in recent years as a result of its perceived effects on forest health. Forest roads can potentially have a number of harmful effects on forest health, including the disruption of natural hydrological processes, increased erosion, or the facilitation of the invasion of forest interiors by exotic plants (Forman 1998, Trombulak and Frissel 2000). Recent studies indicate that forest roads can affect the distribution of forest birds. Rich et al. (1994) in New Jersey found that several forest bird species were less abundant near forest roads than in forest interiors. Similarly, Ortega and Capen (1999) reported that ovenbirds were less abundant near forest roads than in areas away from roads.

Although there is evidence that the construction of forest roads may affect bird distribution, information on reproductive success is important to evaluate the effects of management activities on bird populations (Martin 1992). Forest edges are frequently associated with increases in edge-related nest predation (King et al. 1996, 1999); however, logging roads on the White Mountain National Forest generally did not create large gaps in the forest canopy. Thus, it is unclear whether these roads create the same edge conditions that concentrate predators near edges adjacent to larger openings (King et al. 1998). Similarly, it is unclear whether forest roads create changes in microclimate such as those that are associated with decreases in avian food supplies next to

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more extensive openings (Burke and Nol 1998). Haskell (2000) reported decreases in soil macroinvertebrates adjacent to forest roads in Tennessee; however, it is not known whether these decreases were of a magnitude great enough to affect the reproductive success of forest birds.

We conducted the present study to determine whether forest roads affect nest survival, clutch size, and fledging success of forest passerine birds. Clutch size is known to vary in relation to food abundance in ovenbirds (Zach and Falls 1975) as well as other bird species (Martin 1987), as is the number of young fledged (Rodenhouse and Holmes 1992). Therefore, differences in these parameters between roadside and nonroadside areas will suggest that roads affect arthropod abundance. In addition, we analyzed habitat variables as a function of distance from roads to test whether roads cause changes in habitat that could potentially affect predator abundance and distribution. Finally, we analyzed microclimate variables as a function of distance from roads to test whether roads cause changes in microclimate that could potentially affect arthropod abundance.

Numerous studies have reported that some species of forest birds, including the ovenbird, are less abundant near edges (e.g., Kroodsma 1984). However, it is unclear whether forest birds are actively avoiding edges, or whether they are merely displaced away from edges due to the absence of occupiable habitat beyond edges (Rich et al. 1994, King et al. 1997). This question is difficult to resolve using data on bird distribution, because birds may use edge habitat even if it is suboptimal if interior habitat is saturated, in accordance with the ideal-despotic model of habitat selection (Fretwell 1972). The first birds to arrive on the breeding grounds, however, are unconstrained by conspecifics and should theoretically occupy the highest quality habitat (Best and Rodenhouse 1984). Thus, we also tested whether roadside habitat is suboptimal by comparing nest initiation dates, which we argue correspond to arrival dates, between roadside and nonroadside areas.

Study Area

The study was conducted from May to July in 1999 and 2000 at six sites on the USDA Forest Service Bartlett Experimental Forest in Carroll County, New Hampshire (44°04′N, 71°17′W). Birds were studied at each site in 1 of 2 yr. The Bartlett Experimental Forest is part of the White Mountain National Forest, which is 303,930 ha in extent and is 97% forested (USDA Forest Service 1986). All sites were located in mature northern hardwoods forest.

Methods

Nests were located by following females carrying nesting material or food, or returning to nests to incubate after bouts of foraging, or by directed searching. Nests were marked with a small strip of red flagging tape 3–5 m distant, and were checked every day from ≥5 m away to avoid affecting nest fate. Nests were considered successful if the nest was found empty and the adults were located feeding young. Conversely, nests were considered to have been depredated if the contents were missing before the predicted fledging date, and we were unable to locate adults feeding young. We calculated nest survival rates using the Mayfield (1975) estimator.

Distance from the nearest road was measured for each nest using a measuring tape, or in several cases, by averaging 100 readings from a global positioning system (GPS) receiver and using the waypoint command to calculate the distance between the nest and a similarly averaged point on the nearest road. Previous trials with the GPS receiver at known locations indicated that it was accurate to within 3–5 m, which was sufficient accuracy to confidently assign nests to distance classes. We defined roadside areas as 0–150 m from roads and nonroadside areas as >150 m from roads to correspond to the distance classes used by other studies of the effect of roads on forest birds (Ortega and Capen 1999). We also compared all parameters between 0–75 m and >75–150 m from maintained roads to ensure we weren't overlooking edge effects that might exist within the larger distance classes.

Roads on our study sites consisted primarily of 2- to 4-m wide maintained gravel roads with no maintained shoulders. There was also an 8-m wide paved road with a 1- to 2-m wide maintained shoulder that passed through two of the sites. We did not have enough nests adjacent to paved roads to subdivide the data between paved and unpaved roads. We believe the inclusion of a wider road is likely to increase our chances of detecting a difference in bird reproductive success. There were also numerous unmaintained dirt logging roads ≤2 m wide on our study sites that had leaf litter and herb cover similar to the surrounding forest. It is unlikely these smaller roads affect forest birds because they did not create gaps in the forest canopy and thus probably did not create an edge in any meaningful sense of the word. However, we repeated the analyses of avian reproductive success using distance classes based on the distance to the nearest road of any type to make sure. Finally, we repeated the analyses using distance classes based on the distance to the nearest nonroad edge, which in this study included recent clearcuts, log landings and, in one case, a residence.

Although analyses of nest survival were based on nests of all species, the ovenbird was selected for analyses of nest initiation date, clutch-size, and fledging success to avoid species-specific variation in these parameters that would potentially confound these analyses if all bird species were included. The ovenbird is a suitable study subject for this purpose because other studies have reported that ovenbirds are less abundant near roads (Rich et al. 1994, Ortega and Capen 1999) and thus are likely to show a response to roads if roads do in fact affect habitat quality. Ovenbirds were captured upon arrival at our study sites and fitted with a unique color-band combination. We assumed that ovenbirds would choose the highest quality habitat upon first arrival (Best and Rodenhouse 1984). Arrival dates were difficult to determine, however, because arriving birds, many of which were unbanded upon arrival, moved extensively and occupied territories temporarily in areas other than where they ultimately bred.

Therefore, we used the date of initiation of first clutches (defined as the date when the first egg was laid) instead of arrival dates. We assumed that clutches would be initiated earlier on territories that were occupied earlier because later nesting is associated with lower nestling recruitment and allows less time for the laying of replacement clutches (Verhulst et al. 1995). We ranked ovenbird nest initiation dates as the number of days after the initiation of the first nest at that site to control for variation among years and sites in nesting phenology. We compared nest survival between roadside and nonroadside areas using two-sample *t*-tests (several sites had nests in only one distance class, preventing us from using a paired test). We compared ovenbird nest initiation dates, clutch-size, and fledging success between roadside and nonroadside areas using ANOVA nested by site. All variables were tested for normality and equality of variances prior to analyses. Finally, we calculated *a posteriori* power analyses by calculating the least significant difference detectable given our sample size (Cohen 1988).

We measured vegetation and microclimate variables in 2000 at each of the six sites on four transects extending from the roadside 100 m into the forest. Transects were 50 m apart, with the first transects at each site located at a randomly chosen point along the road. Vegetation measurements were taken at 1, 5, 15, 50, and 100 m from the roadside, and microclimate data taken at 1, 5, 15, and 50 m from the roadside. The following vegetation measurements were taken on 1 m^2 circular plots: canopy coverage (using a spherical densiometer), litter-depth, number of woody stems ≥ 1.5 m tall and ≤ 2.5 m diameter at breast height (dbh), and percent herb cover (estimated to the nearest 10%). We used HOBO® H-8 data loggers to measure the following microclimate variables: temperature, relative humidity, dew point, and light intensity. These data loggers were accurate to $\pm 0.77 C^{\circ}$, ±5%, and ± 0.19 lumens/m^2 for temperature, relative humidity, and light intensity measurements, respectively. Accuracy of dewpoint measurements was not available from the manufacturer. Twenty measurements of all of these variables were made simultaneously at each point along the transect and values averaged for each distance within each site. We used one-way ANOVA to compare habitat and microclimate variables among distances, after testing for normality and equality of variances.

Results

We found 62 nests of the following species: ovenbird, hermit thrush (*Catharus guttata*), swainson's thrush (*Catharus ustulatus*), black-throated blue warbler (*Dendroica cerulescens*), veery (*Catharus fucescens*), least flycatcher (*Empidonax minimus*), blue-headed vireo (*Vireo solitarius*), red-eyed vireo (*Vireo olivaceus*), myrtle warbler (*Dendroica coronata*), and black-throated green warbler (*Dendroica virens*). The average probability of a nest surviving for one day was 0.966 (SE = 0.006), which translates to an average probability of a nest surviving a typical 23 day nesting cycle to fledging of 0.45.

Nest survival rates for all species did not differ between roadside (0–150 m) and nonroadside (>150 m) areas for either maintained or unmaintained roads, although nest survival was marginally higher in roadside areas near unmaintained roads (Table 1). Nest survival was higher within 0–75 m than >75–150 m of maintained roads ($t_{(1,6)} = 2.57, P = 0.04$), and did not differ between 0–75 m and >75–150 m of unmaintained roads ($t_{(1,8)} = 0.77, P = 0.46$). Nest survival did not differ between areas near nonroadside edges and areas in the forest interior (Table 1), and did not differ between 0–75 m and >75–150 m from nonroad edges ($t_{(1,8)} = 0.13, P = 0.90$).

We found 29 ovenbird nests during the 2 yr of the study. Ovenbirds initiated nesting over a 27 day period at the start of the breeding season. Ovenbird clutch size averaged 4.16 eggs (SE = 0.13), and on average, 4.31 (SE = 0.18) young fledged from successful ovenbird nests. Neither ovenbird nest initiation dates, clutch size, nor number of young fledging per successful nest differed between roadside (0–150 m) and nonroadside (>150 m) areas for either maintained or unmaintained roads (Table 2), and none of these parameters differed between 0–75 m and 75–150 m from either maintained or unmaintained roads ($P \geq 0.42$). Similarly, none of these parameters differed between areas near (0–150 m) and far (>150 m) from nonroadside edges (Table 2). Due to the extensively forested nature of our study sites, there were too few nests within 150 m of nonroad edges to meaningfully subdivide these analyses further.

Canopy coverage was arcsine-transformed, and stem density, light intensity and temperature were log-transformed prior to analyses to improve normality. There were no differences among measurements of canopy ($F_{(4,25)} = 0.39, P = 0.82$), litter depth ($F_{(4,25)} = 0.19, P = 0.94$), stem density ($F_{(4,25)} = 0.77, P = 0.56$), or herb cover ($F_{(4,25)} = 0.79, P = 0.54$) at 1, 5, 15, 50, and 100 m from the edges of maintained roads (Figure 1). Similarly, there were no differences among measurements of light intensity ($F_{(3,18)} = 0.69, P = 0.57$), relative humidity ($F_{(3,18)} = 0.53, P = 0.67$), temperature ($F_{(3,18)} = 0.55, P = 0.65$), or dew point ($F_{(3,18)} = 0.74, P = 0.54$) at 1, 5, 15, and 50 m from the

Table 1. Nest survival for all bird species as a function of distance from forest roads and edges on the Bartlett Experimental Forest, New Hampshire, 1999–2000.

	Distance from road or edge					
	0–150 m		>150 m			
	Mean (SE)	*n*	Mean (SE)	*n*	*t*	*P*
Nest survival						
Maintained	0.963 (0.015)	35	0.932 (0.014)	27	1.50	0.17
Unmaintained	0.963 (0.013)	45	0.923 (0.016)	17	2.00	0.08
Nonroad edges	0.958 (0.015)	15	0.960 (0.013)	47	0.13	0.90

Table 2. Ovenbird nest initiation date, clutch size and fledging success as a function of distance from forest roads and edges on the Bartlett Experimental Forest, New Hampshire, 1999–2000.

	Distance from road or edge					
	0–150 m		>150 m			
	Mean (SE)	*n*	Mean (SE)	*n*	*F*	*P*
Nest initiation						
Maintained	6.63 (2.21)	10	5.94 (2.56)	6	0.26	0.78
Unmaintained	7.57 (1.70)	13	3.25 (2.69)	3	0.26	0.78
Nonroad edges	10.5 (2.34)	5	5.87 (1.81)	11	0.54	0.67
Clutch size						
Maintained	4.08 (0.25)	12	3.97 (0.27)	12	1.20	0.34
Unmaintained	4.18 (0.21)	18	3.60 (0.37)	6	1.92	0.18
Nonroad edges	4.00 (0.28)	5	4.40 (0.20)	19	0.67	0.58
Fledging success						
Maintained	4.33 (0.27)	7	4.05 (0.27)	6	0.48	0.64
Unmaintained	4.42 (0.15)	10	3.75 (0.22)	3	0.48	0.64
Nonroad edges	4.25 (0.41)	3	4.52 (0.29)	10	0.99	0.42

edges of maintained roads (Figure 2; error degrees of freedom for microclimate analyses is ≠ 20 because of equipment malfunction at two sample points).

Discussion

The absence of increased nest predation near roads in our study may be attributable to the fact that the roadsides we studied did not share characteristics of other types of edges near which nest predation rates were found to be higher. For example, permanent edges adjacent to agricultural or suburban development may develop vegetation structure distinct from areas away from edges that may concentrate nest predators (Gates and Gysel 1978). Although the forest roads in our study were permanent, with the exception of the one paved secondary road included in the study, they did not create large gaps in the forest canopy. Therefore, these edges were not associated with differences in vegetation structure that might concentrate nest predators at edges near more extensive forms of disturbance. Furthermore, food resources that may attract nest predators to edges adjacent to suburban or agricultural development, such as waste grain or garbage, are absent in the roadways we studied. The observation by Rich et al. (1994) that there were no differences in predator abundance between roadside and nonroadside areas adjacent to 8 m wide roads in New Jersey is consistent with the view that forest roads within this width range do not concentrate nest predators. The higher nest survival rates that we observed near roads in our study may be the result of an aversion on the part of nest predators to roads, or alternatively, an association between nest survival and other habitat features that we did not measure.

Rich et al. (1994) reported greater brown-headed cowbird (*Molothrus ater*) abundance near roads, especially roads with grassy shoulders. In forested landscapes such as northern New England, cowbirds are scarce (Coker and Capen 1995, Yamasaki et al. 2000), and therefore the facilitation of cowbird invasion of forest areas in landscapes such as the White

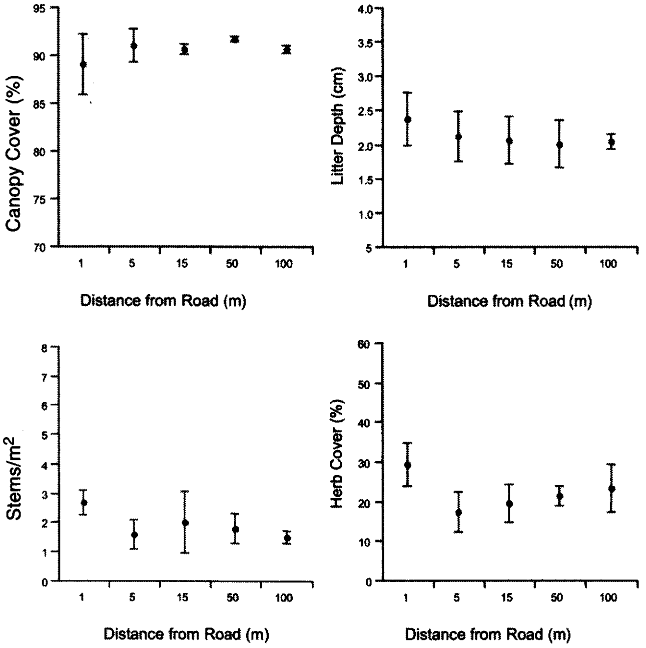

Figure 1. Mean (±SE) values for vegetation variables as a function of distance from maintained forest roads at six sites in the White Mountain National Forest, New Hampshire, 2000.

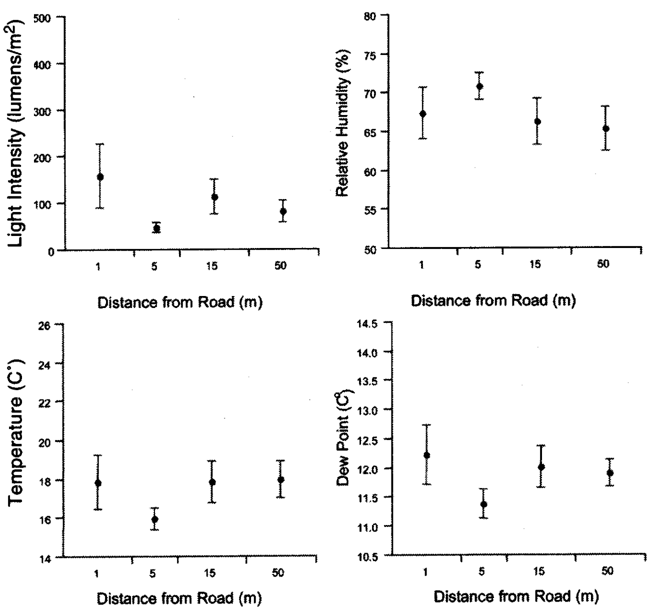

Figure 2. Mean (±SE) of values for microclimate variables as a function of distance from maintained forest roads at six sites in the White Mountain National Forest, New Hampshire, 2000.

Mountain National Forest is not likely an important factor affecting avian reproductive success. In contrast, the construction of roads in regions where cowbirds are abundant might facilitate the invasion of interior forest by these brood parasites (Gates and Evans 1998).

Because clutch size and fledging success are often reported to be related to food abundance in ovenbirds (Zach and Falls 1975) as well as other bird species (Martin 1987, Rodenhouse and Holmes 1992), our observation that these parameters did not differ between roadside and nonroadside areas suggests that ovenbirds at our sites are not affected by reductions in food availability in roadside areas. In fragmented landscapes, the isolation of remnant habitat patches by an expanse of nonnative vegetation is associated with increases in solar radiation and wind (Saunders et al. 1991), which may negatively affect arthropod abundance (Klein 1989). Decreases in invertebrate food resources appear to affect the distribution and reproductive success of forest birds in fragmented landscapes (Burke and Nol 1998, Zanette et al. 2000). In contrast, the roads in our study sites did not create large gaps in the canopy and were not associated with changes in microclimate reported from fragmented landscapes. Haskell (2000) reported decreased abundance of soil macroinvertebrates near forest roads in Tennessee; however, most (ca. 60%) of the decreases in arthropods he observed appeared to be limited to ≤15 m from forest roads. The fact that decreases in arthropod abundance extend a relatively short distance from roads relative to the diameter of an ovenbird territory (ca. 100 m) may explain the lack of differences in reproductive success in roadside and nonroadside areas reported by Ortega and Capen (1999), as well as the lack of differences in ovenbird reproductive output observed in this study.

Our analyses of ovenbird nest initiation dates relative to roadsides indicate that ovenbirds do not actively avoid edges. Ovenbirds even nested beyond the edge of the forest in the grassy shoulder of a paved secondary road ($n = 3$), as well as in unmaintained roads ($n = 3$). Nevertheless, ovenbirds could use roadside habitat even if roadside habitat were suboptimal, if nonroadside habitats were occupied by dominant individuals (Fretwell 1972). If this were the case, then we would predict that nests would be initiated later in roadside areas because subdominant individuals arrive later (Francis and Cooke 1986). In contrast to this prediction, we did not observe any relationship between ovenbird nest initiation dates and distance to the nearest road, indicating that ovenbirds do not actively avoid roadsides.

We observed no relationship between distance from roadsides and habitat characteristics. In contrast, Haskell (2000) reported that litter depth was lower near roadsides in Tennessee. Murcia (1995) cited several reasons for disagreement among studies of edge effects, including differences in edge age, physiognomy, orientation, matrix type, management history, and matrix. Given that Haskell's study was conducted on a national forest in eastern deciduous forest, edge age, physiognomy, matrix type, management history, and matrix were likely similar to the conditions at our sites. Haskell did not specify the orientation of the edges that he studied; however, of our sites, one faced north, one south, and four west. Changes in microclimate near edges are most pronounced at south-facing edges (Matlack 1993), thus, if Haskell's study included a large proportion of south-facing edges, this might account for the more pronounced edge effects that he reported. Alternatively, the differences between our results and those of Haskell may reflect regional differences in plant species composition or climate. Further study on the relationship between road attributes and roadside vegetation and microclimate, as well as regional analyses of these phenomena, would greatly increase our understanding of the generality of these effects.

Because the absence of statistically significant differences in nest initiation date, clutch size, or fledging success may simply reflect the commission of a type II error, such a result can only be meaningfully interpreted with a consideration of statistical power analyses (Cohen 1988). The pairwise analyses of ovenbird reproductive success between roadside and nonroadside areas had 80% power to detect a 26% difference in clutch size and a 17% difference in fledging success (80% power is considered an optimal value in power analyses because higher power leads to spurious results; Cohen 1988). Thus, we are confident that no substantial differences in avian productivity were overlooked due to insufficient power. In contrast, we would need a difference in nest initiation dates of >100% to achieve 80% power to detect a difference in this parameter. Although the mean values for nest initiation dates between roadside and nonroadside areas do not suggest later arrivals by ovenbirds in roadside areas, the power of this comparison was insufficient to demonstrate statistically even large differences in this parameter.

Our results indicate that small (≤8 m wide) forest roads had no negative effects on reproductive success of forest passerine birds nearby, and that there is no evidence that ovenbirds, a species known to be sensitive to fragmentation, actively avoided nesting near roads within this width range. Finally, we detected no relationship between habitat or microclimate and distance from roads. Although small forest roads on our study sites do not appear to affect forest passerine birds, the effects of forest roads appear to vary with road width (Haskell 2000). Evidently, the widths of forest roads on our study sites were below the threshold at which significant negative effects on forest birds appear (Rich et al. 1994). The effects of roads also appear to vary with road density (Forman 1998). Our observation that forest roads had no significant effects on forest passerine birds in the Bartlett Experimental Forest, where road density is 1.7 km/km^2, suggests that on the rest of the White Mountain National Forest, where the overall road density is much lower (0.44 km/km^2), the impact of forest roads on forest passerine birds is negligible.

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