

Forest fragmentation and avian nest predation in forested landscapes

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Summary. The size of forest fragments, the use of land bordering fragments, and the distance of nests from an edge all affect the frequency of predation upon bird nests in Maine (USA), an area where the forest has been fragmented by roads, but not significantly reduced in area. We placed artificial nests containing quail eggs in forests of different sizes and at various distances from the edge to test which of these factors was most important in describing predation. Predation was greatest in small tracts surrounded completely by land. Large areas and those bordered on at least one side by a large water body had lower predation rates. This suggests that influx of predators from nearby habitats may be responsible for much of the nest predation in forest fragments.

Key words: Forest fragmentation – Nest predation – Maine – Artificial nests – Passerines

Clearing of forested land for fields, roads, and powerlines may create a series of small, isolated pieces of forest, a process that has been referred to as “forest fragmentation”. There has been much concern that fragmenting large tracts of continuous forest into disjunct habitat islands may lead to the impoverishment of regional biotas (e.g. Burgess and Sharpe 1981; Harris 1984; Verner et al. 1986). However, with few exceptions (Lovejoy et al. 1986; Rosenburg and Raphael 1986) the research has been undertaken in landscapes where the forest has been both fragmented and significantly reduced in area. This leaves open the possibility that forest fragmentation does not lead to a loss of biological diversity in areas that have been dissected by roads, fields, and other small openings yet still remain extensively forested (Haila and Hanski 1984).

The most extensive documentation of the impact of forest fragmentation has been for migratory passerine birds (e.g., Moore and Hooper 1975; Forman et al. 1976; Galli et al. 1976; Whitcomb et al. 1981; Lynch and Whigham 1984) although plants, mammals, and some insect taxa have been studied too (e.g., Hoehne 1981; Levenson 1981; Matthiae and Stearns 1981; Lovejoy et al. 1986; Murphy and Wilcox 1986). One reason advanced for the impact on birds is that nesting success is less in forest fragments

than in larger forests (Ambuel and Temple 1983). Wilcove (1985) found that the size of the forest fragment and the use of surrounding land affected the number of artificial nests preyed upon; Wilcove worked in a region where non-forested ecosystems predominate. We replicated Wilcove's experiment in Maine, a region where forests cover 90% of the landscape (Powell and Dickson 1984), and are generally fragmented only by roads, fields, and bodies of water. We also examined whether distance from an edge influenced nesting success because some studies have shown nest parasitism by the brown-headed cowbird (*Molothrus ater*) (Brittingham and Temple 1983) and nest predation (Gates and Gysel 1978) to be greater near an edge or forest opening than farther into the forest.

Methods

The study was conducted in June and July of 1985 on eight sites in rural parts of Sagadahoc and Lincoln counties in mid-coastal Maine (Table 1). These sites were separated from the surrounding forest by fields, powerlines, roads, or bodies of water. A road or stream was considered to be an edge if it could be identified from aerial photographs or U.S.G.S. topographic maps. The study areas were classified by type of edge: surrounded entirely by land or small streams; bordered on one side by a large body of water (wider than 10 m).

Aerial photographs from 1980 (1:40000 scale) and U.S.G.S. topographic maps (1:62500) were used to determine the area and edge length of each site (Table 1). To calculate the percentage of forested land within a 3-km radius, we measured the area of land and forested land within a 3-km radius of each site's center, i.e., excluding large bodies of water. One method of quantifying edge relates the shape of a site to a circle (Patton 1975). This edge/area index was calculated by multiplying circumference of the site by the square root of 2π times the area, i.e.,

$$\text{Edge/area index} = \text{circumference} \times \sqrt{2\pi \times \text{area}}$$

Most of the study areas were dominated by red oak (*Quercus rubra*) and white pine (*Pinus strobus*) interspersed with areas of eastern hemlock (*Tsuga canadensis*) and American white birch (*Betula papyrifera*) or yellow birch (*B. lutea*). The Powerline Triangle study area, however, had an overstory of red maple (*Acer rubrum*) and white pine with an understory of northern white cedar (*Thuja occidentalis*).

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Table 1. Characteristics of the forests studied

Study site	Location	Total nests	Boundary	Area (ha)	Edge/area Ratio	Forested Land (%)	Predation (%)
Powerline triangle (PT)	43° 59' 34" N, 69° 48' 22" W	27	Land	20	1.17	79	33.3
Newcastle ridge (NR)	44° 04' 29" N, 69° 34' 18" W	100	Land	240	1.91	78	27.0
Towesic neck (TN)	43° 55' 59" N, 69° 47' 54" W	45	Land	40	1.64	66	22.2
East Nequasset (EN)	43° 56' 46" N, 69° 45' 56" W	36	Water	70	1.23	85	15.6
West Nequasset (WN)	43° 56' 58" N, 69° 46' 52" W	80	Water	70	1.70	84	11.3
Holt forest (HF)	43° 52' 14" N, 69° 46' 07" W	100	Water	100	1.28	77	12.0
Deer meadow (DM)	44° 05' 30" N, 69° 32' 38" W	100	Land	1040	2.23	78	9.0
Robinhood cove (RC)	43° 49' 54" N, 69° 45' 01" W	100	Water	340	1.89	85	3.0

We measured predation on the study areas following Wilcove's (1985) techniques. Our artificial nests were wicker baskets, 10 cm wide by 6 cm deep, which are ordinarily used in aviculture. We lined the nests with pine needles and placed three Japanese quail (*Coturnix coturnix*) eggs in each. To reduce human scent, the nests were left outdoors for 5 days, and eggs were rinsed with well water. Both nests and eggs were thereafter handled only with rubber gloves. Nests were placed in the field by researchers wearing rubber boots and gloves.

All nests were placed on the ground under branches or low plants or beside logs and trees. The nests were placed 15 m apart, along transects that extended into the forested study sites at right angles to the edge. The transects were 80 m apart at Deer Meadow, 85 m apart at Powerline Triangle, and 100 m apart at the remaining study sites. Their lengths varied from 120 m to 360 m.

We inspected the nests 5 days after we placed them in an area and again after 3 more days. A nest was considered to be preyed upon if any of the eggs were missing or destroyed. If a nest had been disturbed on both visits or if more than one egg was destroyed, we considered these disturbances to be interdependent and so recorded the predation only once. We compared predation rates with the size of each site by a Spearman's rank correlation. To facilitate a comparison with Wilcove's (1985) results we also compared the number of nests from which at least one egg was destroyed after 8 days and the number of undisturbed nests using Pearson chi-square (Wilcove 1985). We compared predation between all possible pairs of sites with Pearson chi-square or with Fisher's exact test when the minimum estimated expected value was less than 20. A significance of $p=0.05$ was used to detect trends.

Results

Predation rates differed among the eight study sites (Pearson chi-square: $p < 0.0001$). A Spearman's rank correlation showed that the number of nests preyed upon was negatively correlated with the size of the site ($r = -0.7202$, $p < 0.05$). Newcastle Ridge, which was the third largest area and had

the second highest predation rate, seemed to be an exception to this pattern. This was clearly demonstrated by the change in the coefficient of rank correlation that occurred when Newcastle Ridge was removed from the analysis ($r = -0.9375$, $p < 0.01$). Predation rates thus seemed to be related to the size of the forest tracts, but exceptions like Newcastle Ridge suggest that area effects did not account for all of the variation. Pearson chi-square tests comparing predation rates between all possible pairs of sites (Wilcove 1985) yielded similar results.

A stepwise logistic regression (Dixon 1983) compared the relative importance of each study area's boundary type, area, edge/area ratio, percent of forested land within 3 km, as well as the distance of each nest from the edge. The type of boundary, the area, and the interaction term between boundary type and area were most important in predicting the amount of predation in a forest tract (Table 2). Predation was greater in forests bordered by land than on sites bordered on at least one side by a large body of water, and decreased with increasing area.

The edge/area ratio and the distance of each nest from an edge did not affect the predation rates (improvement chi-square: $p > 0.05$) when the stepwise logistic regression was performed for all sites. Examination of each transect separately also showed no discernible pattern of predation with respect to edge. A separate regression for the four fragments bordered by land indicated that predation in-

Table 2. Results of a stepwise logistic regression relating the characteristics of study sites to the amount of nest predation

Characteristic	Equation coefficient	Improvement chi-square p	Goodness-of-fit chi-square p
Constant	-1.1646	0.000	0.052
Location		0.000	0.184
Land	0.3445		
Water	-0.3445		
Area	-0.0036	0.000	0.495
Area-location interaction	0.0022	0.042	0.569

creased as distance from an edge increased (improvement chi-square: $p = 0.045$) for sites surrounded by land. We cannot explain this and suspect that it is an anomaly of the data.

We identified a predator as a bird if the eggs had holes pecked into them with no toothmarks evident. Chewed eggshells, toothmarks on shells, or a damaged nest were indicative of mammalian predation (Anderson 1971). We identified the predator as either a bird or a mammal for 56% ($n = 47$) of the disturbed nests. Of these nests, 11% were destroyed by birds, 89% by mammals. Although we did not identify each predator, red fox (*Vulpes fulva*) and red squirrel (*Tamiasciurus hudsonicus*) were observed at the study sites, and sign of both skunk (*Mephitis mephitis*) and raccoon (*Procyon lotor*) were seen beside damaged nests.

Discussion

Our results support Wilcove's (1985) suggestion that the size of a forest tract is important in predicting the rate of nest predation in a tract. Wilcove speculated that densities of small predators may be greater in small woodlots than in larger forest fragments, and that nest predators may move into the fragments from nearby habitats. Our results suggest that the latter may be more important because forests near bodies of water had less predation than did forests that were more accessible from nearby habitat. Foxes, skunks, and raccoons are opportunists, using a wide variety of habitats (Matthiae and Stearns 1981), and may well be moving into small forests from surrounding lands, possibly using the edges of powerlines and roads as travel corridors. Bodies of water also seem to be capable of fragmenting forests, though to a lesser extent than do terrestrial openings, suggesting that some predators may also be travelling along shorelines. The possible movement of predators into small forests would be expected to affect the predation rates of small mammals and birds, as well as of nests.

We found no evidence that nest predation was greater near an edge than in the forest. This may be because few of the nests were preyed upon by birds, and avian nest predators, such as common crows (*Corvus brachyrhynchos*) and common grackles (*Quiscalus quiscula*), are commonly found near edges (Whitcomb et al. 1981). In summary, our results imply that all birds nesting on the ground in small forests, not just those nesting near the edge, will be affected by the large predation rates. Furthermore, fragmentation influences predation rates in landscapes where forests are dominant.

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