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PREDATION ON ARTIFICIAL NESTS IN HURRICANE-CREATED GAPS AND ADJACENT FOREST OF THE SOUTHERN APPALACHIANS

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Abstract: Predation rates were compared during three 7-day trials on 742 artificial ground nests located in 10 hurricane-created canopy gaps and IO adjacent closed-canopy controls in the southern Appalachian mountains of North Carolina. White northern bobwhite (*Colinus virginianus*) eggs were used in trials 1 and 2, but brown-speckled Japanese Quail (*Coturnix coturnix*) eggs were used in trial 3 to determine: (1) whether artificial ground nests were at a greater risk of predation in gaps than in adjacent closed-canopy forest; (2) whether predation rates increased with successive trials and; (3) whether egg color affected predation rates. Horizontal shrub cover and vertical shrub density up to 1.5 m were greater in gaps than in controls. Seventy percent of artificial nests were depredated, but predation rates ranged from 0-100% among sites and trials in both gaps and controls. Predation rates did not differ between gaps and controls. However, predation rate increased from trial 1 to trials 2 and 3. Egg color did not influence predation rates of artificial nests. Vertical shrub density deterred nest predation in gaps (but not controls), in trials 1 and 2, but had little effect by trial 3. Forest fragmentation by canopy gaps did not adversely affect nesting success of ground-nesting birds, as measured by predation rates of artificial ground nests.

Key Words: artificial nests; nest predation; egg color; gaps.

INTRODUCTION

The southern Appalachian mountains contain a large proportion of the forested land in eastern North America (Alig et al., 1990), and the diversity of breeding neotropical migratory birds is among the highest in the United States (Franzreb and Rosenberg, 1997). Many species of breeding birds are declining in the southern Appalachians, particularly among ground-nesters and species associated with young second-growth forest and canopy gaps within forests (Franzreb and Rosenberg, 1997; *but see* James, 1998). Several factors influence songbird population

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dynamics, including adult and juvenile survival, fecundity, and nest success (Donovan and Thompson, 2001). Nest predation may contribute to the decline of breeding neotropical migratory birds in the United States (Thompson et al., 1995).

Several studies suggested that nest predation and parasitism rates are higher in edge habitat and in fragmented landscapes (Paton, 1994). Forest fragmentation increased the proportion of edge to interior in small remaining woodlands, and changed the landscape matrix surrounding them. However, results varied among nest predation studies conducted in different geographic locations and landscape contexts (Paton, 1994). Donovan et al. (1997) suggested that this variation may because of one or several of four factors: (a) landscape context; (b) local predator community; (c) local breeding bird community (as hosts to nest parasitism and as prey for predators); and (d) nest site microhabitat structure. Bayne and Hobson (1997) and Thompson et al. (1995) indicated that nest predation and parasitism rates in edge habitat were lower within forested than agricultural landscape contexts where populations of nest predators and nest parasites, brown-headed cowbirds (*Molothrus ater*), are higher.

Small canopy gaps created by natural disturbance are an important component of habitat heterogeneity in many eastern deciduous forests, including the southern Appalachians (Greenberg and Mcnab, 1998), and provide important habitat for some bird species associated with interior edges and early seral stages (Franzreb and Rosenberg, 1997; Thompson et al., 1995; Greenberg and Lanham, 2001). Spring and fall migrants are concentrated in gaps, presumably because of higher fruit and insect abundance (Blake and Hoppes, 1986; Kilgo et al., 1999; Martin and Karr, 1986; Wunderle, 1995). Greenberg and Lanham (2001) found that density and species richness of breeding birds is higher in gaps than in adjacent closed canopy forest (using the same study sites as this study), likely because of an abundance of insects, nest-building materials, and nest sites.

Edge characteristics also may influence nest predation (Suarez et al., 1997). Gates and Gysel (1978) suggest that abrupt edges function as an ecological trap by concentrating nests, resulting in high mortality by nest predators. Most studies of nest predation along forest edges were conducted at long linear edges such as roadways (Bergin et al., 1997; Yahner and Mahan, 1996), clearcuts (King et al., 1998; Yahner and Mahan, 1996), or forest-field edges (Donovan et al., 1997; Paton, 1994).

Despite their prevalence, canopy gaps have been largely overlooked as an important contributor to edge within forested landscapes. Little is known about how forest fragmentation created by treefall gaps influences predation rates on artificial ground nests. Small canopy gaps (about 1-9 treefalls) in the eastern United States created by background tree mortality (versus catastrophic disturbance) occupied an estimated 9.5% of old-growth forests (Runkle, 1982). Greenberg and McNab (1998) estimated 0.28% of the forested National Forest land in the southern Appalachians was damaged in 1995 by a single high-intensity storm, Hurricane Opal. The few studies that have addressed artificial nest predation in small forest gaps used anthropogenically created gaps such as group selection cuts (Kilgo et al., 1999; King et al., 1998). No studies have examined rates of nest predation in canopy gaps created by natural disturbance.

Egg color could bias results of artificial nest predation studies. Conspicuous, white eggs such as those of northern bobwhite (*Colinus virginianus*) could enhance predation rates relative to better-camouflaged brown or speckled eggs. Yahner and Mahan (1996) found lower predation of artificial nests containing brown versus white chicken eggs.

Artificial ground nests were used as an index of whether nest predation rates were higher in extensive canopy gaps with indistinct boundaries than in adjacent closed-canopy forest in the southern Appalachian mountains of North Carolina. The study tested: (1) whether artificial ground nests were at a greater risk of predation in gaps than adjacent closed-canopy forest; (2) whether predation rates increased with successive trials within study sites and; (3) whether egg color affected predation rates.

METHODS

Study area and study plots.-Our study site was located at the Hent Creek Experimental Forest, a 2500-ha watershed within the Pisgah National Forest near Asheville, North Carolina. Elevations ranged from 700-1070 m. Annual precipitation averaged 120 cm and was evenly distributed throughout the year. Winters were short and mild, summers were long and warm. Common tree species on xeric sites included scarlet oak (*Quercus coccinea*), chestnut oak (Q. *prinus*), black oak (Q. *velutina*), blackgum (*Nyssa sylvatica*), sourwood (*Oxydendrum arboreum*), and occasional pines. Tulip poplar (*Liriodendron tulipifera*) and northern red oak (Q. *rubra*) dominated moist slopes and coves. Red maple (*Acer rubrum*), hickory (*Carya* spp.), dogwood (*Cornus florida*) and white oak (Q. *alba*) were common throughout (Greenberg and McNab, 1998). Most of the forested area was SO-120 yrs old.

Nest predation was studied in 10 randomly selected forest canopy gaps and adjacent forested controls ≥25 m (most were ≥50 m) from gap edges. Gaps were created by storms associated with Hurricane Opal in October 1995, and ranged from 0.2-l. 1 ha. They resulted from multiple tree windfalls (uprooted and broken trees) that caused a 19–39% reduction in tree density and a 30–53% reduction in basal area. Hence, gaps were irregular in shape with indistinct boundaries and contained multiple standing trees (Greenberg and McNab, 1998). A detailed description of some study gaps is provided in Greenberg and McNab (199X).

Potential nest predators include the American crow (*Corvus brachyrhynchos*), blue jay (*Cyanocitta cristata*), eastern chipmunk (*Tamias striatus*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginianus*), gray fox (*Urocyon cinereoargenteus*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), white-footed mouse (*Peromyscus leucopus*) and other small mammals, and several species of snakes.

Habitat measurements.—The vertical profile density of vegetation was measured using a shrub cover board (Hays et al., 1981) in eight gaps and controls. Measurements were taken at five equidistant points spaced at least 10 m apart along a centrally located transect in each gap and reference area. Profile estimates were categorized into one of five shrub density classes (0, 1–25%, 26–50%, 51–75%, 76–100%), for 0.5 m increments from ground level to 2 m. Percent horizontal shrub cover (extent of ground coverage by shrubs) was determined in all gaps and controls using five randomly located 15 m line transects within each site. Shrubs were defined as any woody vegetation <2-m tall. Canopy cover was determined in all study gaps and controls using a spherical densiometer at five equidistant points spaced at least 10 m apart along transects. Basal area was calculated from diameter at breast height (dbh) measurements of all trees > 12.5-cm dbh measured at all study sites in rectangular plots ranging in size from 0.2-0.96 ha, depending on the size and shape of gaps. Plot sizes were the same in gaps and paired controls.

Nest predation experiments.—Three, 7-day nest predation trials were conducted with a minimum 7-day interval between trials from 19 May-28 June 1998. Artificial ground nests were constructed within each gap and forested control along transects at 20-m intervals. Nests were indentations in the leaf litter, containing two eggs. Latex gloves were worn to minimize human scent while constructing nests and handling eggs (Whelan et al., 1994). Small plastic flags were placed 2 m from each nest to help in relocation. All flagging and nest materials were removed after each trial. The same transects and approximate nest placement locations were used in each trial. Nests were considered depredated if they had missing or damaged eggs.

The number of nests per site, as permitted by the size and shape of gaps, ranged from 8-18. Each reference area received the same number of artificial nests as its adjacent gap, and the same number of nests was used in each trial. Northern bobwhite eggs were used in trials 1 and 2. During trial 3 nests were provisioned randomly with eggs of northern bobwhite (white) or Japanese quail (*Coturnix coturnix*) (brown-speckled), such that half of the nests contained white eggs and half contained brown-speckled eggs at each site.

Statistical analyses.—Paired t-tests compared means of canopy cover, vertical shrub density, horizontal shrub cover, and basal area between gaps and controls. The proportion of depredated nests in each study site and trial was calculated and tested for differences in predation rates between treatments (gaps vs. controls), among trials, and treatment X trial interaction using a univariate analysis of repeated measures design. Treatment (f = 0.13, d.f. = 1, p = 0.7200) and treatment X trial interaction (f = 0.66, d.f. = 2, p = 0.5200) were not significant, so data for both treatments were combined and tested for differences in predation rates among trials using a univariate analysis of repeated measures design with least squares means. A two-way analysis of variance (ANOVA) was used to examine the effect of egg color, treatment, and treatment X egg color interaction effects on nest predation rates in trial 3. A simple linear regression examined relationships between habitat structure and nest predation rates among gaps and controls for each trial. The relationship between gap size and predation rates for each trial was also examined using simple linear regression. All proportion data were arcsine square-root transformed for analyses. A $p < 0.10$ determined significance.

RESULTS

Basal area and canopy cover were lower in gaps than controls, whereas percent horizontal cover of shrubs was greater in gaps (Table 1). Vertical shrub density up to 2.0-m height was significantly greater in gaps than controls. Vertical shrub density was greatest from O-0.5 m above ground, and decreased in both treatments with successive height increments (Table 1). Vertical shrub density from ground level to 0.5 m was significantly correlated with horizontal shrub cover (r = 0.71, p = 0.0020, n = 20).

A total of 70% (n = 516) of all artificial nests (n = 742) were depredated (one

Table 1. Structural characteristics (mean ± SE) of canopy gaps and adjacent closed canopy controls at the Bent Creek Experimental Forest, Asheville, North Carolina in 1998.

Structural Feature	*n*	Treatment: Gaps	Treatment: Controls	*p*
Live basal area (m^2/ha)	10	11.6 ± 1.5	24.9 ± 1.3	0.0006
Percent canopy cover[a]	10	69.4 ± 2.1	89.6 ± 1.7	0.0002
Percent shrub cover (horizontal)[a]	10	54.9 ± 5.9	25.5 ± 3.1	0.0009
Percent shrub density (vertical profile, m)				
0–0.49	8	41.7 ± 6.6	16.5 ± 3.3	0.0066
0.5–0.99 m	8	24.X ± 5.4	4.9 ± 1.6	0.0121
1.0–1.49	8	11.8 ± 2.x	3.1 ± 1.6	0.0388
1.5–2.0	8	9.1 ± 2.4	4.1 ± 2.1	0.0552

[a] Data are presented as actual means but were square-root arcsine transformed for paired f-tests.

or both eggs removed or damaged). Predation rates ranged from 0–100% in both gaps and controls. Predation rates at some sites were consistently 100% for each trial, whereas others never exceeded 29%. If nests were depredated, both eggs were usually (n = 498, 97%) removed; only one egg was removed in 1.9% of all cases. Peck holes were observed in 1.9% of eggs remaining after nest predation. Eggshells were observed near depredated artificial nest sites 3.7% of the time.

Predation rates on artificial nests did not differ significantly between gaps and controls (f = 0.13, d.f. = 1, p = 0.7230), nor was there an effect of treatment X trial interaction (f = 0.066, d.f. = 2, p = 0.5231). However, there was a significant effect of trial on predation rates of artificial nests (f = 7.65, d.f. = 2, p = 0.0017) (Fig. 1). Repeated measures ANOVA of trial effects with least squares means using pooled treatment data indicated a significant increase (f = 19.57, d.f. = 29, p = 0.0001) in predation rates from trial 1 to trials 2 and 3 (Fig. 1). There was no effect of egg color (f = 0.03, d.f. = 1, p = 0.8748), treatment (f = 0.03, d.f. = 1, p = 0.8588) or color X treatment interaction effect (f = 0.40, d.f. = 1, p = 0.5330) on nest predation rates (mean range 72.5 ± 11.0 to 81.1 ± 9.2 for both egg colors and treatments).

Basal area had no detectable effect on nest predation rates in closed canopy controls (p ≥ 0.8784 for each trial) or gaps (p ≥ 0.6817). Percent horizontal shrub cover did not influence nest predation rates in controls (p ≥ 0.5945). Shrub cover in gaps (where horizontal shrub cover was significantly greater) deterred nest predation in trials 1 (p = 0.0800, r = 0.58) and 2 (p = 0.0700, r = 0.59), but this function was not apparent by trial 3 (p = 0.3900, r = 0.30 Gap size did not influence predation rates in any trial (p ≥ 0.2094).

DISCUSSION

Forest fragmentation by canopy gaps did not adversely affect nesting success of ground-nesting birds, as measured by rates of artificial ground-nest predation. Donovan et al. (1997) found higher predation rates in edges within highly or moderately fragmented landscapes than in unfragmented landscapes. Because our 2500 ha study area was largely forested, the proportion of edge created within and along the boundaries of canopy gaps was slight.

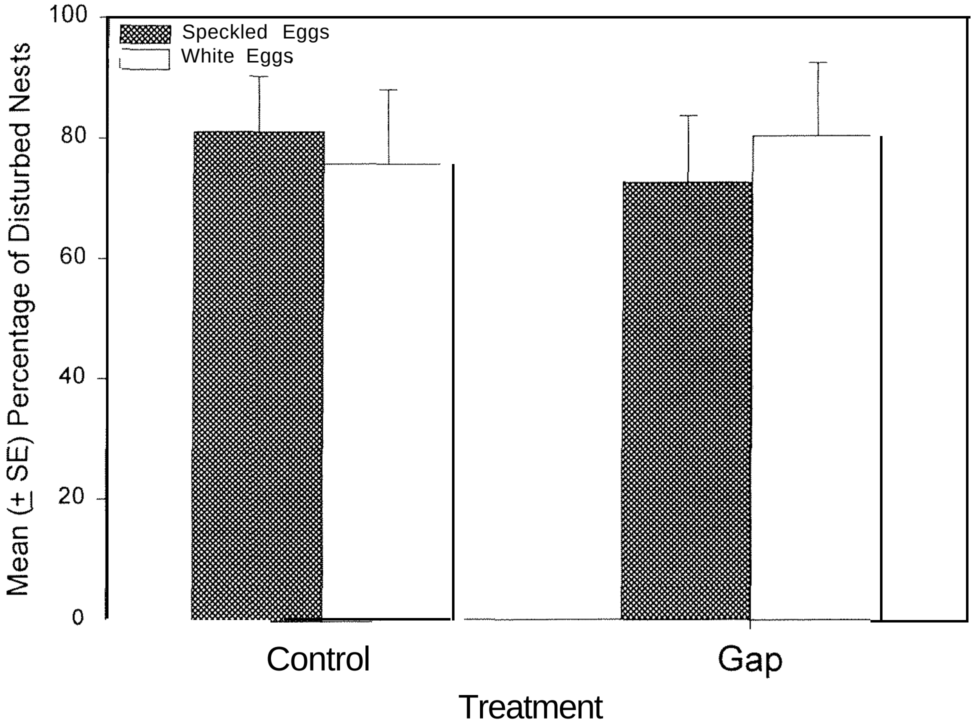

FIG. 1. Mean (±SE) percentage of artificial ground nests disturbed in downburst-created gaps (n = 10) and forested controls (n = 10) in three 7-day trials at the Rent Creek Experimental Forest, Asheville, North Carolina in 1998.

The type and degree of edge contrast with adjoining habitats also may affect rates of artificial nest predation (Saracco and Collazo, 1999; Suarez et al., 1997). Suarez et al. (1997) found that the predation rates of indigo bunting (*Passerina cyanea*) nests along abrupt edges was almost double the rate in gradual edges such as along streamsides, and in gaps created by treefall or selective logging. Suarez et al. (1997) reported higher nest predation rates along abrupt edges of small openings than along gradual edges of small forest openings. King et al. (1998) reported higher predation rates on artificial nests in edges created by group selection cuts (a closely spaced series of 0.5-I .O-ha forest openings wherein all trees are removed) than in interior forest. However, edge created by group selection cutting differed from the amount and type of edge resulting from naturally created gaps with high residual tree density. The high number of residual trees and indistinct boundaries of the study gaps may have "softened" the contrast between gaps and surrounding forest, effectively reducing any potential edge response by nest predators.

Nest predation rates were significantly lower in trial I than in trials 2 and 3. This suggested that predators may develop a search image that improved foraging efficiency after the first trial. The marginally significant negative relationship between horizontal shrub cover and nest predation rates suggested habitat complexity provided by a heavier shrub cover contributed to lower predation levels. Dion et al. (2000) found that vegetative characteristics influenced depredation rates on natural nests, but not on artificial nests, suggesting that predators perceived the two nest types differently. They also found that rates of nest depredation, in relation to vegetative characteristics, differed among predators. Bowman and Harris (1980) also reported that spatial heterogeneity was important in reducing nest predation by raccoons, but with experience they reduced their search time for artificial ground nests. Vegetative cover can influence what predatory species are present, and affect movement (Schranck, 1972), and visual and olfactory detection of nests by predators (Crabtree et al., 1989; Dion et al., 2000; Vander Lee et al., 1999). Any initial advantage that higher shrub cover conferred to artificial nest survival in study gaps did not result in lower predation rates by trial 3.

Artificial ground nests at the Bent Creek Experimental Forest were subjected to similar rates of predation regardless of egg color. This suggested that predators within the study area responded to search image cues other than egg color. Conversely, Yahner and Mahan (1996) found that artificial nests containing brown chicken eggs were depredated with half the frequency of nests containing white chicken or northern bobwhite eggs. Egg fate in relation to color may depend upon the species of predator(s) that occur within the neighborhood of artificial nests.

Nest success has an important influence on whether songbird populations increase, decrease, or remain stable (Donovan and Thompson, 2001). Small irregularly shaped gaps within a forested context that retain a partial canopy and have indistinct boundaries do not adversely affect predation rates on artificial ground nests. Landscape context, size and edge-type appear to influence the response of nest predators, and the effect of forest fragmentation in the southern Appalachians.

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