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Depredation of artificial avian nests in irrigated forests.—Predation is a major factor reducing avian nesting success (Ricklefs 1969). Greater vegetative density near avian nests may reduce predator foraging efficiency, thereby lowering incidences of depredation of nests (Bowman and Harris 1980, Sudgen and Beyersbergen 1986, Yahner and Cypher 1987). Further, avian predators on nests tend to predominate in forested habitats, whereas mammalian predators are more common in farmland habitats (Angelstam 1986). Our previous studies have shown that American Crows (*Corvus brachyrhynchos*) and Blue Jays (*Cyanocitta cristata*) were major predators on artificial avian nests placed in even-aged forest stands, and mammals were relatively unimportant as predators (Yahner and Voytko 1989, Yahner et al. 1989). Moreover, because corvids locate food resources via vision, arboreal nests in even-aged stands are more susceptible to disturbance than ground nests (Yahner and Scott 1988). In order to understand better long-term trends in regional populations of avifauna, more attention should be given to relationships among vegetative density near nest sites, habitat type in which nests are located, and relative abundance of predators associated with a particular habitat type (Picman 1988).

A portion of state game lands (SGL) 176, Centre County, Pennsylvania, has been irrigated with chlorinated sewage effluent (hereafter termed wastewater) since 1983 (Rollfinke et al. 1990). As a consequence of this irrigation, vegetative structure is considerably different between irrigated and nonirrigated forest stands (Rollfinke et al. 1990). The irrigated sector of SGL 176 is approximately a 50:50 intermix of forest and farmland/old field habitat types (Rollfinke et al. 1990) which likely affects the relative abundance of avian versus mammalian predators on avian nests compared to more forested sites in the region (after Angelstam 1986). Diversity and abundance of breeding birds are much higher on irrigated than nonirrigated forest stands at SGL 176, suggesting that irrigated stands are better habitats than nonirrigated stands (Rollfinke et al. 1990). However, the "quality" of irrigated stands for breeding birds cannot be assessed fully until information on productivity and survivorship is obtained (Van Horne 1983). Thus, our objective was to compare depredation of artificial ground and arboreal nests placed in forest stands irrigated with wastewater to those placed in contiguous nonirrigated stands. These findings will be valuable in assessing the impact of forest irrigation on regional bird populations.

Study area.—Our study was conducted on an irrigated and an adjacent nonirrigated forest stand at SGL 176, Centre County, Pennsylvania (hereafter both stands are referred to collectively as the Toftrees area). The irrigation system occurred on 200 ha and contained 3100 rotating sprinklers connected by a parallel network of pipes, each spaced 25 m apart. The system applied about 264 cm of wastewater annually compared to an average annual precipitation of 93 cm (Rollfinke et al. 1990).

Forest stands on the Toftrees area were approximately 50 to 60 years old and consisted principally of mixed-oak (*Quercus* spp.) and red maple (*Acer rubrum*). Major woody stems (<2.5 cm diameter) on irrigated and nonirrigated stands included red maple, black cherry (*Prunus serotina*), white sassafras (*Sassafras albidum*), and *Rosa* spp. Percent coverage of herbaceous vegetation was much greater on the irrigated (57%) than on the nonirrigated stand (5%) ($P < 0.01$). A lush herbaceous layer grew to a height of 1–2 m on the irrigated stand and was comprised principally of white snakeroot (*Eupatorium rugosum*), common pokeberry (*Phytolacca americana*), and Canada clearweed (*Pilea pumila*).

Common avian species nesting less than 2 m from ground level on the Toftrees area included Ruffed Grouse (*Bonasa umbellus*), Wood Thrush (*Hylocichla mustelina*), Ovenbird (*Seiurus aurocapillus*), Common Yellowthroat (*Geothlypis trichas*), Hooded Warbler (*Wil-*

sonia citrina), Northern Cardinal (*Cardinalis cardinalis*), Indigo Bunting (*Passerina cyanea*), and Rufous-sided Towhee (*Pipilo erythrophthalmus*) (Rollfinke et al. 1990).

Methods.—Thirty random sites each were selected on irrigated and nonirrigated stands during five time periods (trials) from May to July 1989. Minimum distance between sites was 25 m, and each site was greater than 50 m from a disturbance, such as an old field or a clearcut stand. On the irrigated stand, sites were midway between parallel pipelines. Of the 30 sites per stand during each trial, 15 were randomly selected for placement of ground nests and 15 for placement of arboreal nests.

A nest consisted of two fresh, brown chicken eggs (Yahner et al. 1989). Ground nests were placed next to the nearest stump, log, or tree in a slight depression in leaf litter (Yahner and Wright 1985); arboreal nests were put in cups (chicken wire, 10 cm × 10 cm deep), which were lined with leaf litter and attached 1.5 m above ground to the nearest woody stem (1–5 cm dbh) (Yahner and Cypher 1987).

The fate (undisturbed, disturbed by an avian predator, or disturbed by a nonavian predator) of each nest was determined five days after placement (Yahner et al. 1989). A disturbed nest had a broken or missing egg by day 5. Nest or egg appearance and mode of disturbance were used to categorize predators as avian or nonavian (Rearden 1951, Yahner and Wright 1985, Yahner and Cypher 1987). We wore rubber gloves and boots when placing nests to reduce human scent near nests. Because nests were visited only when placed, paths in vegetation were not developed by investigators. Nests, eggs, and egg fragments were removed at the end of a trial.

The influence of forest irrigation (irrigated vs nonirrigated stand), nest type (ground vs arboreal), and time period (trials 1–5) on nest fate was analyzed by 2- to 4-way tests-of-independence (BMDP4F, Dixon 1985). Likelihood ratios (G^2) were computed to test for interactions between nest fate and the three other variables using log-linear models, which is appropriate when examining attribute variables in multi-way contingency tables (Sokal and Rohlf 1981, Dixon 1985). We counted the numbers of American Crows and Blue Jays that were 200 m or less from field personnel during time of placement and removal of nests during each trial. Relative numbers of these avian predators were compared to those noted in previous studies (Yahner and Scott 1988, Yahner et al. 1989).

Results.—Of 300 nests, 237 (79%) were disturbed during the five trials (Table 1). Only five (2%) of the disturbed nests were affected by avian predators; the remaining 232 (98%) nests were likely disturbed primarily by mammalian predators, e.g., raccoons (*Procyon lotor*), based on mode of distance.

Nest fate was not associated with forest irrigation, nest type, or time period. One hundred twenty-one (81%) and 116 (77%) of the nests placed in irrigated and nonirrigated forest stands, respectively, were disturbed ($G^2 = 0.68$, $df = 2$, $P = 0.71$) (Table 1). One hundred twenty (80%) of the ground nests and 117 (78%) of the arboreal nests were disturbed ($G^2 = 0.37$, $df = 2$, $P = 0.83$). Numbers of disturbed nests per trial ranged from 42 (70%) in trial 2 to 51 (85%) in trial 5 ($G^2 = 10.95$, $df = 14$, $P = 0.69$). Numbers of American Crows and Blue Jays per trial averaged 5.2 (range = 3–8) and 0.4 (range = 0–1), respectively.

Discussion.—Depredation rate (79%) of nests on irrigated and nonirrigated stands combined at the Toftrees area was higher than those noted in several other studies of predation on either artificial or natural nests. For instance, our previous studies of artificial ground and arboreal nests in even-aged forest stands less than 10 km from the Toftrees area reported rates of nest disturbance by predators ranging from 31–61% (Yahner and Cypher 1987, Yahner and Scott 1988, Yahner et al. 1989). Depredation rate of natural songbird nests on these same even-aged stands over a 3-year period was 48% (Yahner, unpubl. data). Wray et al. (1982) noted that 43% of nests established by four species of grassland sparrows were lost to predators. Yahner (1982) recorded that 44% of American Robin (*Turdus migratorius*)

TABLE 1
 NUMBER OF GROUND AND ARTIFICIAL NESTS DISTURBED BY PREDATORS DURING FIVE TRIALS ON AN IRRIGATED FOREST STAND AND A NONIRRIGATED FOREST STAND AT STATE GAME LANDS 176, CENTRE COUNTY, PENNSYLVANIA, 1989

| Trial (dates) | Nest type* | Irrigated | Nonirrigated |
|---------------------|------------|-----------|--------------|
| 1 (24-29 May) | Ground | 12 | 12 |
| | Arboreal | 12 | 9 |
| 2 (7-12 Jun) | Ground | 11 | 12 |
| | Arboreal | 12 | 7 |
| 3 (21-26 Jun) | Ground | 13 | 13 |
| | Arboreal | 12 | 11 |
| 4 (5-10 Jul) | Ground | 10 | 14 |
| | Arboreal | 13 | 13 |
| 5 (19-24 Jul) | Ground | 12 | 11 |
| | Arboreal | 14 | 14 |
| All trials combined | Ground | 58 | 62 |
| | Arboreal | 63 | 54 |
| | Total | 121 | 116 |

* N = 60 nests per trial divided equally between stands and nest types (ground vs arboreal).

nest and 68% of Mourning Dove (*Zenaid macroura*) nests were lost to predators. In contrast, Best (1978) found that 76% of the nests created by Field Sparrows (*Spizella pusilla*) were preyed upon. Redmond et al. (1982) observed considerable differences in predation on nests between two races of Spruce Grouse (*Canachites canadensis*), with a 70% nest loss in *C. c. franklinii* but only a 19% loss in *C. c. canace*.

The irrigated stand at the Toftrees area contained an abundant and a diverse breeding-bird community, in part due to the ready availability of foraging sites and food resources (Rollfinke et al. 1990). However, because depredation of artificial nests was pronounced throughout the Toftrees area, both the irrigated and the proximal nonirrigated stand may be relatively low in "quality" to breeding birds (after Van Horne 1983). But data on avian productivity of natural nests at the Toftrees area would be necessary to support or refute this contention.

Depredation rate of nests at the Toftrees area was probably not influenced by lush herbaceous vegetation on the irrigated stand. Other studies have shown that avian nests were less susceptible to predation when located in dense vegetation, which either impeded foraging efficiency of predators or provided increased concealment (e.g., Bowman and Harris 1980, Yahner and Wright 1985, Sugden and Beyersbergen 1986).

In contrast to studies of depredation of artificial nests on even-aged forest stands near the Toftrees area (e.g., Yahner and Scott 1988, Yahner et al. 1989), most disturbed nests (98%) at the Toftrees area were affected by nonavian predators. Yahner and Scott (1988), for example, found that 72% of the disturbed nests in even-aged stands were attributed to avian predators. Perhaps this differential impact of mammalian vs avian predation on nests is explained partially by habitat type on the two areas. The Toftrees area contained an intermix of forest and farmland/old field cover types, whereas even-aged forest stands in the previous studies were surrounded on 95% of their boundaries by forest. Hence, the Toftrees area,

with a great percentage of farmland, might be expected to have a lower number of avian than mammalian predators (Angelstam 1986). Although numbers of American Crows at the Toftrees area were comparable to those in even-aged stands in the region (e.g., \bar{x} = 4.8 crows per trial, range = 2–9; Yahner et al. 1989), numbers of Blue Jays, which are considered a principal predator of avian nests (e.g., Picman 1988), were virtually absent from the Toftrees area. Yahner et al. (1989), for instance, recorded much higher numbers of Blue Jays in even-aged stands (\bar{x} = 10.5/trial, range = 0–12) than at the Toftrees area.

We attribute most nest predation on the Toftrees area to mammals, particularly raccoons, for three reasons. First, a comparable number of ground and arboreal nests were preyed upon. If birds were the principal predators, we would expect greater numbers of arboreal nests to be lost rather than ground nests (e.g., Yahner and Scott 1988). Raccoons are capable of climbing woody stems to reach nests, and bird eggs are an abundant and easily accessible food resource to raccoons (Greenwood 1981). Second, raccoons were the principal large mammalian predator captured on the Toftrees area (Brown 1989). Although raccoon density on our study area probably was similar to some other sites in Pennsylvania (C. L. Brown, pers. comm.), density was likely higher than on the xeric, even-aged forest stands examined in previous studies (Yahner and Scott 1988, Yahner et al. 1989). Third, a greater density of raccoons might be expected at the Toftrees area because of abundant water and food resources (see Sanderson 1987). Several small ponds formed on the irrigated stand at Toftrees area as a result of irrigation, and farm crops (e.g., corn), invertebrates, and berries were abundant (Rollfinke et al. 1990).

Because rates of depredation did not increase over time, we do not believe that raccoons or other mammalian predators were using human scent to locate nests. Further, because depredation rate did not vary among trials, we believe that predators did not learn over time to better exploit the irrigated and nonirrigated stands with artificial nests nor did they improve their ability to find nests by developing a search image for nests (Yahner and Wright 1985).

In conclusion, differences in vegetative structure resulting from forest irrigation did not affect depredation rates of artificial avian nests, at least within the immediate study area. This finding is valuable in understanding the impacts of habitat alterations on long-term trends in avian population numbers (Whitcomb et al. 1981) because application of wastewater to forest stands is expected to increase in the future as a viable means of waste disposal (Nutter and Red 1986). We concur with other investigators (e.g., Bowman and Harris 1980, Picman 1988) that comparisons of predation rates among habitats in future studies should include a consideration of the relative abundance of predators because foraging strategies are species- or taxon-specific, and hence, their impact on avian nests (ground vs arboreal) may vary on a localized scale.

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