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Flock structure of wintering birds in an irrigated mixed-oak forest.—Wastewater (chlorinated effluent) irrigation in northern latitudes presumably can affect flock structure of wintering forest birds because of ice buildup on understory stems and lower branches of overstory trees and breakage of these foraging substrates (Sopper and Kardos 1973, Dressler and Wood 1976, Rollfinke and Yahner 1990). Although avian flock structure in winter has been studied in eastern deciduous forests (e.g., Morse 1970), nothing is known about how these aspects of wintering birds in eastern forests may have been altered by wastewater irrigation. In this study, we tested the hypothesis that flock structure (size and composition) of wintering birds did not differ between irrigated (with ice cover present versus absent) and nonirrigated forest stands.

Study area and methods.—Our study was conducted on a 200-ha section of State Game Lands (SGL) 176, Centre County, Pennsylvania, during the winters of 1986–1987 and 1987–1988. Forest stands were 50-to-65 years-old, and dominant overstory trees included white (*Quercus alba*), chestnut (*Q. prinus*), scarlet (*Q. coccinea*), north (*Q. rubra*), and black oaks (*Q. velutina*); red maple (*Acer rubrum*), bigtooth aspen (*Populus grandidentata*), and pine (*Pinus* spp). Major understory and shrub species included white sassafras (*Sassafras albidum*), black cherry (*Prunus serotina*), and red maple (see details in Rollfinke and Yahner 1990). The irrigation system consisted of about 3100 rotating sprinklers connected by a network of buried and surface lateral pipes. The system pumped up to 15 million L of wastewater daily (Matula 1983) and applied about 264 cm of wastewater to the soil annually, thereby tripling mean annual precipitation. Ambient temperatures in Centre County seldom fall below $-18°C$, and mean January temperature is $-2.8°C$ (Matula 1983). Therefore, in the irrigated stand, appreciable ice cover (up to 15 cm thick and reaching 3–4 m in height above ground) often occurred on understory and ground-level vegetation when ambient temperatures were low (Rollfinke 1988).

We established four 250-m transects each in irrigated and adjacent nonirrigated forest stands. Transects were walked at a slow pace (≤ 1.5 km/h), and all birds heard or seen within a 50-m lateral distance of each transect were counted. Lateral distances from transects were at least 50 m from disturbances (i.e., unpaved roads) and habitat edges. Birds flying over the forest canopy were not counted. At the beginning of each count, temperature, percent cloud cover, precipitation, and wind velocity were recorded. Counts were not conducted during heavy precipitation or high winds (details of avian counts are given in Rollfinke and Yahner 1990).

Each transect was visited approximately twice per week from late December to early March in both winters. Birds were counted 24 times per winter along each transect at three times of day: eight times each in morning (07:00 to 11:00 h), midday (11:01 to 14:00), and late afternoon (14:01 to 17:30) (Rollfinke and Yahner 1990). When a flock of birds was encountered, numbers of individual birds and species composition were noted. A flock was defined as a group of two or more birds moving together (Morrison et al. 1987).

We compared the number of times each of eight common wintering species was encountered along irrigated and nonirrigated transects combined among three social-group types (solitary bird, single-species flock, and mixed-species flock) using G-tests for goodness-of-fit (Sokal and Rohlf 1981). Expected values were based on equal representation among social-group types. Pairwise chi-square tests-of-independence (Sokal and Rohlf 1981) were used to test for interspecific differences in frequencies of occurrence among the three social-group types. Mean ($\pm$SD) number of birds per mixed-species flock was determined for each common species and for all species combined. Mean ($\pm$SD) number of species and number

TABLE 1

NUMBERS OF OBSERVATIONS OF EIGHT BIRD SPECIES (PERCENT OCCURRENCE IN PARENTHESES) IN IRRIGATED AND NONIRRIGATED STANDS COMBINED, SGL 176, CENTRE CO., PENNSYLVANIA, IN EACH OF THREE SOCIAL-GROUP-TYPES: SOLITARY INDIVIDUALS, SINGLE-SPECIES FLOCKS, AND MIXED-SPECIES FLOCKS IN WINTERS 1986–1987 AND 1987–1988

	Social-group-type[1]		
	Solitary	Single-species	Mixed-species
Downy Woodpecker[a]	67 (42.7%)	12 (7.6%)	78 (49.7%)
Hairy Woodpecker[a]	30 (42.3%)	4 (5.6%)	37 (52.1%)
Black-capped Chickadee[b]	7 (8.0%)	14 (15.9%)	67 (76.1%)
Tufted Titmouse[c]	7 (14.3%)	1 (2.0%)	41 (83.7%)
White-breasted Nuthatch[bc]	12 (13.8%)	6 (6.9%)	69 (79.3%)
Brown Creeper[bc]	8 (11.3%)	6 (8.5%)	57 (80.3%)
Golden-crowned Kinglet[bc]	4 (4.9%)	8 (9.9%)	69 (85.2%)
White-throated Sparrow[d]	6 (13.6%)	22 (50.0%)	16 (36.4%)

[1] Observed versus expected number of observations were significantly different among social-group-types for each of eight species; G-test for goodness-of-fit, $G > 9.2$, df = 2, $P < 0.01$. Species with same letter in superscript were not significantly different among social groups, based on pairwise comparisons of species; chi-square test-of-independence; $\chi^2 < 7.0$, df = 2, $P > 0.05$.

of birds per flock were tested among flocks observed in the irrigated stand when ice cover was present (>50% of understory vegetation covered by ice, Rollfinke 1988), the irrigated stand when ice cover was absent (<50% ice cover), and the nonirrigated stand using single-classification analyses-of-variance (Sokal and Rohlf 1981). The percentages of mixed-species flocks containing each of the common species also were calculated.

Results and discussion.—Observed frequencies of the eight common bird species differed from expected among the three social-group types (Table 1). Five species were observed most often in mixed-species flocks and rarely as solitary individuals or members of single-species flocks. Downy Woodpeckers (*Picoides pubescens*) and Hairy Woodpeckers (*P. villosus*) were observed as single individuals nearly as often as they were found in mixed-species flocks. In contrast, White-throated Sparrows (*Zonotrichia albicollis*) were encountered more often in single-species flocks than in either of the other social-group types.

Four species (Downy Woodpecker, Black-capped Chickadee [*Parus atricapillus*], White-breasted Nuthatch [*Sitta carolinensis*], and Golden-crowned Kinglet [*Regulus satrapa*]) were present in over 50% of all flocks (Table 2). Black-capped Chickadees were the most abundant flock members, in terms of number of individuals per flock, and often led flocks. Mixed-species flocks of songbirds generally form around one or two nuclear species (usually parids), which possess a distinct system of alarm calls (Morse 1970, Gaddis 1980). Although Tufted Titmice (*Parus bicolor*) also were observed leading flocks in our study, they were found in a smaller percentage of all flocks than were chickadees, perhaps because of lower titmouse abundance (see Rollfinke and Yahner 1990).

White-throated Sparrows were observed in only 13% of all mixed-species flocks, yet they were found in larger numbers (up to 15 per flock) than other species. Downy and Hairy woodpeckers, White-breasted Nuthatches, and Brown Creepers (*Certhia americana*) always occurred in low numbers, e.g., never exceeding three individuals each per flock. Most woodpecker species maintain well-defined feeding territories throughout the year (Berner

TABLE 2

MEAN (±SD) NUMBER OF INDIVIDUALS OF EIGHT BIRD SPECIES IN EACH MIXED-SPECIES FLOCK, RANGE OF INDIVIDUAL BIRDS PER FLOCK, AND PERCENT (%) OF FLOCKS CONTAINING A GIVEN SPECIES, BASED ON 123 MIXED-SPECIES FLOCKS IN IRRIGATED AND NONIRRIGATED STANDS COMBINED, SGL 176, CENTRE CO., PENNSYLVANIA, IN WINTERS 1986–1987 AND 1987–1988

Species	Birds per mixed-species flock	Range per mixed-species flock	Percent of mixed-species flocks containing a given species
Downy Woodpecker	1.00 ± 0.89	0–3	63.4
Hairy Woodpecker	0.45 ± 0.77	0–3	30.1
Black-capped Chickadee	2.08 ± 2.40	0–9	54.5
Tufted Titmouse	0.71 ± 1.14	0–4	33.3
White-breasted Nuthatch	0.89 ± 0.90	0–3	56.1
Brown Creeper	0.67 ± 0.80	0–2	46.3
Golden-crowned Kinglet	1.39 ± 1.49	0–6	56.1
White-throated Sparrow	0.69 ± 2.29	0–15	13.0
No. species/flock	3.80 ± 1.86	2–10	—
No. birds/flock	8.20 ± 5.34	2–26	—

and Grubb 1985). If food supplies are adequate, a woodpecker often remains on its territory and joins a foraging flock only when the flock is within its territory. Thus, woodpeckers gain little or no advantage in finding food from participation in mixed-species flocks because they already are familiar with local food supplies (Berner and Grubb 1985). Rather, woodpeckers primarily receive anti-predation advantages, as evidenced by lower levels of vigilance when foraging with flocks of parids (Sullivan 1984). In contrast, tits, nuthatches, creepers, and kinglets do not maintain strict winter territories. Hence, by participating in vagrant flocks, these species benefit from improved chances of finding adequate food resources as well as from reduced time in predator surveillance (Morse 1970).

We observed 123 mixed-species flocks during the two winters. The occurrence of mixed-species flocks of wintering songbirds is a widespread phenomenon, especially in northern environments (Morse 1978, Morrison et al. 1987). Mean flock composition for mixed-species flocks in our study was 8.2 individual birds and 3.8 species (Table 2). Thus, mean flock size and species composition at SGL 176 compared closely with results from other studies: 10.1 birds, 2.5 species in Maine (Morse 1970); 6.2 birds, 3.6 species in Ohio (Berner and Grubb 1985); and 8.8 birds, 2.8 species in California (Morrison et al. 1987). Further, mean numbers of individual birds and species per mixed-species flock were not significantly different among the irrigated stand with ice cover present, the irrigated stand with ice cover absent, or the nonirrigated stand ($F = 0.97$; df = 2, 120; $P > 0.10$ and $F = 1.38$; df = 2, 120; $P > 0.10$, respectively).

Flock formation by songbirds may increase foraging efficiency and decrease predation risk for individual flock members (Sullivan 1984, Berner and Grubb 1985, Morrison et al. 1987). However, other factors, such as mate selection and thermal protection, can influence the decision to join a flock (Morrison et al. 1987). Increased avian participation in mixed-species flocks may be an adaptation to harsh environmental conditions, e.g., unfavorable weather conditions or low food abundance (Morse 1970, Morrison et al. 1987). Conversely, when food resources are abundant, forest birds spend less time in flocks (Morse 1970, Berner and Grubb 1985). Hence, if winter ice cover in the irrigated stand of SGL 176 reduced food availability, birds would be expected to participate in flocks more often in ice-covered than in ice-free stands. However, because no differences were found in flock structure among the three treatments, we suspect that ice accumulation did not limit food availability appreciably for wintering birds on our study sites.

In conclusion, flock structure of wintering birds was not appreciably affected by wastewater irrigation. However, other studies have suggested that irrigation may increase avian density and diversity in both winter and the breeding season but may impact negatively those breeding species that forage and nest in leaf litter (Rollfinke and Yahner 1990).

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