

# THE GROUPING OF NOCTURNAL PASSERINE MIGRANTS

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**ABSTRACT.**—Nocturnal passerine migration was studied with portable ceilometers in the spring and fall of 1974 in northeastern New York. Most passerine migrants seen flew singly. Of the more than 4000 birds recorded in the spring and fall migrations, nearly 60% in both seasons were separated by time intervals greater than 30 sec. Poisson distributions were fitted to the observed bird distributions. Each time line was analyzed with 10- and 30-sec sampling units. In the spring 12.1% of the 66 time lines in the 10-sec series and 13.6% of the 66 in the 30-sec series were significantly clumped ( $P > 0.05$ ). In the fall less flocking was observed, with 3.2% of 93 time lines in the 10-sec series and 4.4% of 91 in the 30-sec series significantly clumped.

Regression analysis showed that flocking, as measured by the coefficient of dispersion, significantly increased with the volume of migration in the spring. Regression of the fall data did not reveal this relationship. Analysis of the time intervals separating birds in the 10-sec sampling units indicated that migrants flying close together assume nonrandom spacing patterns. The groups of birds detected by the 10- and 30-sec units ranged in size from 2 to 13; the majority contained fewer than 6 birds. The 30-sec units did not detect proportionately larger groups, suggesting the flocks were consistently small and compact enough to be largely contained by the 10-sec sampling units.—*Biology Department, State University of New York at Albany, Albany, New York 12222. Present address: 831 Woodland Ave., Schenectady, New York 12309. Accepted 2 December 1975.*

THE horizontal spacing patterns of nocturnal passerine migrants have been the subject of considerable interest to students of migration, but after several decades of work, no consensus has emerged. Ball (1952), Hamilton (1962), and Nisbet (1963) proposed the existence of well-defined nocturnal flocks, while Stone (1906), Lowery and Newman (1955), and Gauthreaux (1972) reported sighting only single passerines at night. In fact, nearly the entire range of possibilities has been suggested, with Eastwood and Rider (1966), Bellrose (1971), and Bruderer and Steidinger (1972) reporting various proportions of single and flocked passerines migrating together.

These results are, perhaps, not surprising considering the problems involved in studying small, fast-moving birds that are traveling under cover of darkness at altitudes of from several hundred to several thousand feet. Indeed, researchers have been resourceful in taking advantage of the limited means available for probing nocturnal migration. Stone (1906), in one of the earliest accounts of nocturnal flocking, took advantage of the light from a great lumberyard fire in Philadelphia to watch spring migrants. The birds he saw were flying singly, but the limited extent of his observations and the possibility that the fire disrupted normal behavior weakened his conclusions. Nocturnal migrants frequently give distinctive calls while flying. Ball (1952) and Hamilton (1962, 1967) have used this phenomenon to study flocking behavior and have noted that the pattern of calling often suggested groups.

Radar and moonwatching have been useful in describing many aspects of migration but they have not provided clearcut evidence on the question of nocturnal flocking. Radar has been ineffective primarily because the width of most radar beams is such that a single target on the PPI screen may represent one bird, a flock of birds, or several unassociated birds. By moonwatching Lowery and Newman (1955) were able to distinguish between single birds and tight flocks. They considered nocturnal groups only in terms of birds simultaneously crossing the moon and thus overlooked diffuse flocks in their conclusion that all passerines migrate singly.

The most recent radar studies of nocturnal grouping have been in Europe: Bruderer and Steidinger (1972) in Switzerland and Eastwood and Rider (1966) in En-

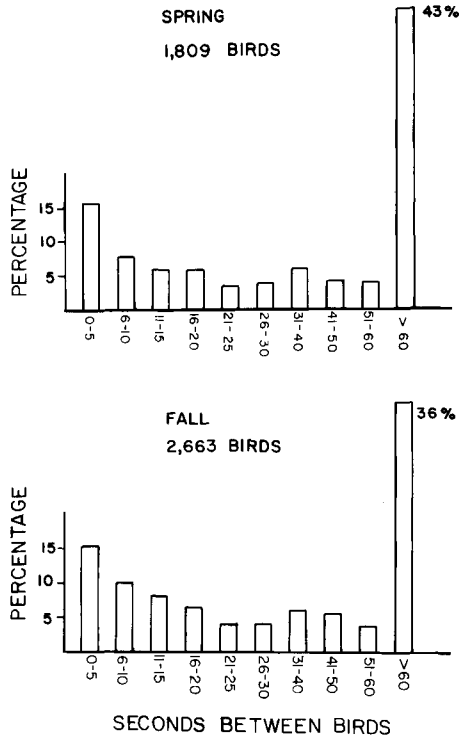


Fig. 1. The frequencies of the time intervals between migrants determined from each time line for the spring and fall migrations.

gland. Their results were not conclusive. Eastwood and Rider found most birds in pseudogroups that either soon disbanded or were an artifact of the radar pulse-volume effect. Bruderer and Steidinger found most birds flying singly but had evidence suggesting that some birds might be migrating in small diffuse flocks.

A weakness common to most previous studies has been their failure to test the dispersion of migrants statistically for clumping and randomness. Studies such as Bruderer's may be particularly liable to this criticism because low levels of clumping are expected in random distributions. The objective of my study was to obtain visual observations in a time sequence that could be analyzed to reveal the spacing patterns of nocturnal passerine migrants.

#### METHODS

I studied nocturnal migrants in the spring and fall of 1974 at Schenectady, New York. In the spring 60 30-minute observation periods were recorded on 26 nights (17 April–5 June) and 85 observation periods were recorded on 42 nights in the fall (26 August–28 October). Migrants were watched with tripod-mounted 10 × 50 binoculars as they passed through the cone of light produced by two 100-watt ceilometers. For details on the construction and use of portable ceilometers see Gauthreaux (1969) and Able and Gauthreaux (1975). The light beam and the field of view of the binoculars were both approximately 7° and were aligned vertically for maximum overlap. The migrants were described in terms of their track direction, and estimated height (low, medium, high). The temporal order of the sightings was maintained by recording the observations on a continuously running cassette tape recorder. The exact time sequence of the migrants was determined by timing the tape playback with a stopwatch. From the tape playback a master time line was constructed representing all the birds observed. This time line contained birds flying in many different directions and thus, to analyze flocking, additional time lines were constructed that contained only those birds heading in approximately the same direction. Migrants were considered moving

TABLE 1  
POISSON DISTRIBUTIONS FITTED TO OBSERVED DATA<sup>1</sup>

	Number of tests	Number significantly clumped	Percent clumped
<b>Fall</b>			
10-sec units	93	3	3.2%
30-sec units	91	4	4.4%
<b>Spring</b>			
10-sec units	66	8	12.1%
30-sec units	66	9	13.6%

<sup>1</sup> Significance determined by G-test ( $P < 0.05$ ).

in the same direction if their tracks were not greater than 60° apart. In most cases the majority of birds in an observation period were contained in one 60° span and thus only one time line was critically analyzed. In a few instances enough migrants were flying in other directions to make it statistically feasible to analyze two time lines from one observation period. These data were analyzed with a Fortran Poisson program, Sokal and Rohlf (1969), on the Univac 1110 at the SUNYA computer center.

Selected observation periods were analyzed with 1-, 5-, 10-, and 30-sec sampling units to determine which unit size would consistently reveal the most flocking (for a discussion of sample size in Poisson analysis see Poole 1974). The 10- and 30-sec units were chosen for use on all the data.

## RESULTS

The spring and fall time lines were first analyzed in terms of the time intervals between successive birds (Fig. 1). This analysis showed that most of the birds were flying singly. In both the spring and fall nearly 60% of the intervals between birds were greater than 30 sec. Though the majority of migrants were widely spaced, over 20% in both seasons were separated by intervals of 10 sec or less. Thus a substantial portion of the birds were relatively close together and potentially flocked.

I examined the data for clumping and randomness by fitting Poisson distributions to the observed distributions of birds. The use of a Poisson distribution requires that a time line format be divided into sampling units of equal length. The observed distribution of birds in these sampling units was then compared to a Poisson distribution and the goodness of fit tested by a G-test (Sokal and Rohlf 1969). As the results obtained in this way can be biased by the size of the sampling unit (Poole 1974), each time line was divided into 10- and 30-sec units to check the consistency of results. If an average ground speed of 30 mph (13.4 mps) is assumed for the migrants (Able MS, Drury and Keith 1962), each 10-sec unit represents a distance of 440 ft (134 m) and each 30-sec unit a distance 1320 ft (402 m). I assumed that clumping too diffuse to be detected by the larger units had little likelihood of being true flocks, i.e. those maintained through time by visual or acoustic contact.

For the fall migration, 93 time lines were analyzed (Table 1). Using 10-sec units, three tests showed significant clumping ( $P < 0.05$ ) while the remaining 90 were randomly spaced. Examining the fall data with 30-sec units revealed 4 of 91 tests

TABLE 2  
POISSON DISTRIBUTION FITTED TO HYPOTHETICAL OBSERVATION PERIOD

Number of birds per 10-sec unit	Observed frequencies	Poisson predicted frequencies
0	139	136.7
1	21	25.7
2	5	2.4

TABLE 3  
POISSON DISTRIBUTIONS FITTED TO POOLED OBSERVATIONS ANALYZED WITH 10-SEC UNITS

	Number of samples	Mean sample	Percent clumped	G-test statistic	df	Significance level
Spring	49	15.8	3.3%	11.07	2	0.005
	8	36.0	6.9%	6.03	2	0.05
	6	51.0	6.1%	34.36	5	0.005
	3	119.3	14.6%	66.40	5	0.005
Fall	72	9.7	5.2%	21.62	3	0.005
	8	39.3	3.0%	1.48	2	N.S.
	13	90.0	3.7%	12.84	4	0.025

significantly clumped. Two of the three clumped periods from the 10-sec series were also found to be significantly clumped using 30-sec intervals.

These results indicate that in a considerable majority of the cases, passerine migrants were randomly spaced in the air. The fall record indicates that only 3.2% of the 10-sec tests and 4.4% of the 30-sec tests showed significant deviation from a random distribution. In the spring, although a majority of the tests revealed random distributions, 12.1% of the 10-sec and 13.7% of the 30-sec tests were significantly clumped. The differences between spring and fall were greatest in the 30-sec series but a Fisher's exact test for independence showed this difference not significant ( $P = 0.07$ ).

To determine the number of birds in a season that may have been flocked, the number of birds from each time line that exceeded or fell short of Poisson predictions was calculated and the results within each season summed. The following example illustrates the calculation for a hypothetical observation period (Table 2). In this observation period 31 birds were seen; in five sampling units two birds were seen, but the Poisson distribution predicted that only 2.4 units or 4.8 birds should be clumped. The difference is thus 10 minus 4.8 or 5.2 birds. Summing such values for the 10-sec series showed that in the spring, 89.3 of 1639 migrants or 5.5% were clumped. In the fall migration, using 10-sec intervals, 73.7 of 2187 or 3.4% were clumped. Considering the 30-sec series, 60.3 of 1590 birds in the fall or 3.1% exceeded random predictions and in the spring 21.8 of 1666 or 1.3% were clumped. The two flocking values for the fall migration are nearly identical and in the spring, though estimates differ by 4%, both values confirm a low level of flocking.

In Poisson analysis the data from individual observation periods may be pooled. Pooled distributions serve as a check on individual results because they may demonstrate a significant nonrandom trend that only approached significance in the single observation periods. In temporal distributions the power of the pooled distribution is somewhat diminished by a distortive interaction between distributions of greatly differing numbers. To minimize this error the spring and fall data were divided into size classes and the pooling done only between observation periods having approximately the same number of birds. The results for the fall and spring data, for the 10-sec series, indicated that six of the seven pooled distributions were significantly clumped (Table 3). The heterogeneity G-statistic in each test was not significant, suggesting that the data as a whole demonstrated a tendency toward significant clumping. In the 30-sec series for the spring and fall, four of seven pooled distributions showed significant clumping, and the heterogeneity G in each case was again insignificant (Table 4).

Analysis of the individual observation periods showed only a small proportion of flocking: 5.5% of the birds in spring and 3.4% in the fall clumped beyond Poisson

TABLE 4  
POISSON DISTRIBUTIONS FITTED TO POOLED OBSERVATIONS ANALYZED WITH 30-SEC UNITS

	Number of samples	Mean sample	Percent clumped	G-test statistic	df	Significance level
Spring	49	13.9	6.0%	4.59	2	N.S.
	7	36.9	1.5%	0.85	3	N.S.
	7	53.0	-2.5%	35.27	6	0.005
	3	118.0	3.9%	122.36	12	0.005
Fall	70	9.2	6.3%	12.44	3	0.01
	10	38.5	2.7%	7.65	3	N.S.
	12	88.9	1.7%	25.19	7	0.005

predictions (10-sec units). The pooled distributions, though in most cases significantly clumped, seemed to corroborate these results. The percent flocking in the pooled data, calculated as shown for the individual observation periods, indicated that for the 10-sec series in the spring, 113 of 1630 migrants or 6.9% were clumped and in the fall 89.1 of 2187 or 4.1% exceeded Poisson estimates. Most of the migrants are thus randomly spaced in both cases. The pooled distributions demonstrated that the low level of clumping is a real and significant trend.

For purposes of the following tests, the coefficient of dispersion (CD) was calculated for each time line. The CD, which is the mean/variance ratio, is less than one in repulsed or regular distributions, greater than one in clumped distributions, and approximately equal to one in random distributions (Sokal and Rohlf 1969: 88).

The mean CD's for the spring 10- and 30-sec series were  $1.084 \pm 0.04$  and  $1.109 \pm 0.20$  respectively. The mean values for the fall 10- and 30-sec series were less:  $1.034 \pm 0.04$  and  $1.058 \pm 0.06$  respectively. The results of *t*-tests between the corresponding 10- and 30-sec series in the spring and fall, showed no significant differences between seasons (10-sec series  $t = 1.505$ ; 30-sec series  $t = 0.902$ ).

The CD values for the 10- and 30-sec series within each season were also compared by *t*-test. No significant differences existed between the 10- and 30-sec series (fall  $t = 0.19$ , spring  $t = 0.41$ ). In addition to suggesting a consistency of results, these tests may indicate that very diffuse flocks, presumably undetectable with 10-sec units, did not prevail over more compact ones as Bruderer and Steidinger observed in Switzerland (1972).

TABLE 5  
NUMBER OF CLUMPS THAT EXCEEDED POISSON PREDICTION IN EACH SIZE CATEGORY<sup>1</sup>

Flock size	10-sec units		30-sec units	
	Number	Percent of total	Number	Percent of total
2	9.2	26.5	5.8	17.2
3	8.9	25.6	8.0	23.8
4	12.2	35.1	3.9	11.6
5	1.5	4.3	4.4	13.1
6	2.9	8.3	1.8	5.4
7			5.0	14.9
8			0.7	2.1
9			1.0	2.9
10			2.0	5.8
11			—	—
12			—	—
13			1.0	2.9

<sup>1</sup> Data drawn from significant tests only ( $P < 0.05$ ), spring and fall combined.

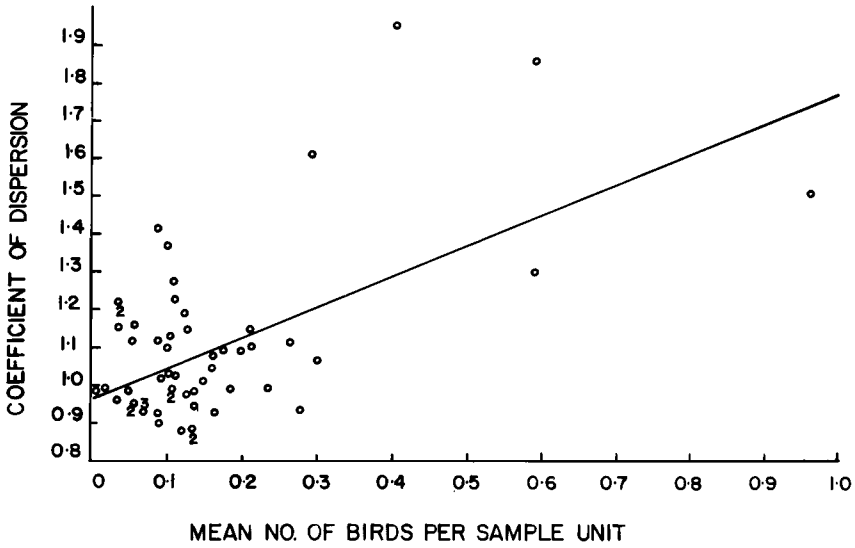


Fig. 2. The coefficient of dispersion for each time line in the spring 10-sec series plotted as a function of the mean number of birds per sample unit. Regression analysis showed that flocking increased with the number of birds observed ( $r^2 = .37, t = 6.11, P < 0.001$ ).

Several observers (Bellrose 1971, Bruderer and Steidinger 1972) have suggested that flocking may increase with the number of birds in the air. To test this possibility with my own data the CD from each time line was plotted as a function of the mean number of birds per sample unit. The plots of the spring and fall 10-sec data (Figs. 2 and 3) show a tendency for the flocking to increase with the volume of migration only

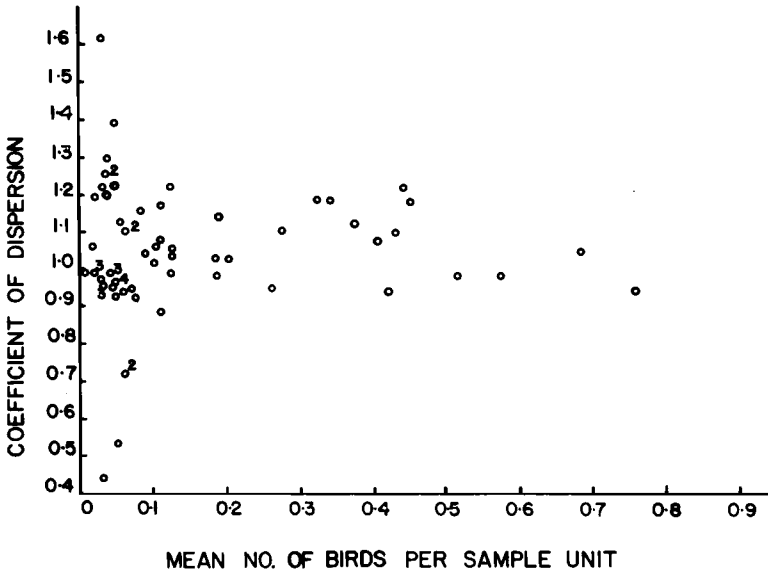


Fig. 3. The coefficient of dispersion for each time line in the fall 10-sec series plotted as a function of the mean number of birds per sample unit. Regression analysis showed no tendency for the flocking to increase with the volume of migration.

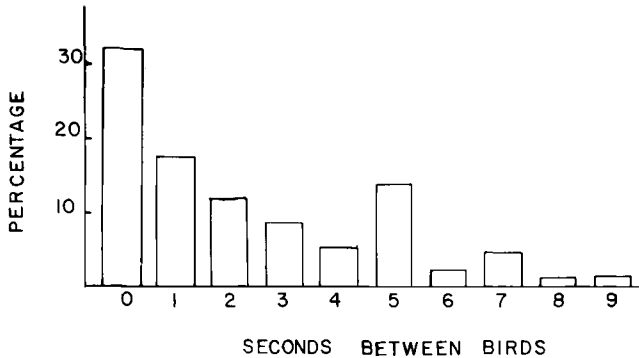


Fig. 4. Frequency of each interval within each 10-sec unit containing two or more birds expressed as the percentage of the total intervals examined.

in the spring period. A regression analysis of the spring data indicated a significant dependence of flocking on migration volume ( $t = 6.11$ ,  $P < 0.001$ ,  $r^2 = 0.368$ ). A regression of the fall points revealed no significant relationship. Regression analysis of the spring and fall periods in the 30-sec series showed similar results with a significant relationship in the spring ( $t = 5.486$ ,  $P < 0.001$ ,  $r^2 = .319$ ) and none in the fall. These results suggest a seasonal behavioral difference with only spring migrants showing a tendency toward greater flocking as migration volume increases.

To determine how migrants utilize space when they are clumped, each of the 10-sec units that contained more than one bird was examined for the time intervals that separated the birds. The pooled results (Fig. 4) suggested a tendency for birds to be closely clumped with 32% observed at the same time. Closer analysis was attempted by examining the 10-sec units having two birds. These comprise the majority of the units having more than one bird. The frequencies of the time intervals between birds for the two-bird units were compared to the frequencies expected by random distribution (Fig. 5). A G-test indicated that the observed frequencies were significantly different from random ( $P < 0.05$ ,  $df = 9$ ,  $G = 17.03$ ). Figure 5 shows the tendency for more birds to appear simultaneously than expected (0 sec) but also more birds with wider separation than predicted (5 and 7 sec). These results may indicate that night flocks, like day flocks (Heppner 1974), involved tightly clumped groupings and formations with regular spacing.

The actual size of nocturnal flocks was impossible to determine with my method of analysis, but the 11 significant periods in the combined spring and fall 10-sec series and the 13 in the 30-sec series were examined for the number and size of the nonrandom groups that were recorded (Table 5). In the 10-sec series, the clumps ranged in size from two to six. The four-bird group showed the highest percent of the total: 35.1%. The two-, three- and four-bird groups combined accounted for 87.4% of all the clumps that exceeded Poisson predictions. In the 30-sec series the clumps ranged in size from 2-13. The largest group, as a percent of the total, was the three-bird class: 23.8%. The units having two to seven birds accounted for 88% of the clumping. The 30-sec units were three times the length of the 10-sec units but the clump sizes recorded in the larger units were not proportionately greater than those in the 10-sec series. This suggests that the flocks were generally small, usually less than six birds, and that the greater portion were compact enough so that the 10-sec sample units almost entirely contain them. The flock size in both 10- and 30-sec series increased with the volume of migration.

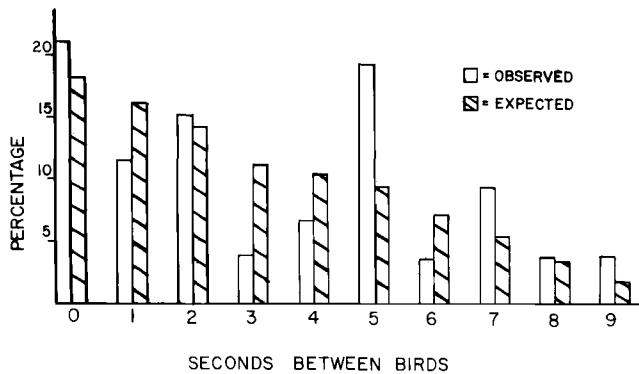


Fig. 5. Frequencies of the time intervals between birds for the 10-sec units containing two birds compared to those expected by random distribution. A G-test showed the differences to be significant ( $P < 0.05$ ).

The data were also inspected for evidence that the time of night, time of year, or degree of cloud cover might influence flocking but no such correlations were found.

#### DISCUSSION

Many visual studies of migration have been made in the past by moonwatching or ceilometers but none before mine obtained data in a temporal framework that permitted the investigation of compact and diffuse flocking. Lowery and Newman (1955) stated that only 1.1% of their 7432 spring lunar observations involved more than one bird and, although there was "a tendency of [the] birds to come in bursts," they felt no passerine flocking was indicated. Their percentage value has not been corrected for the number of birds one would expect to be clumped in a random distribution nor have birds flying in different directions been eliminated. These adjustments, necessary in estimating flocking, would considerably reduce their figure. My data indicate a greater percentage of migrants in spring and fall may have been flocked. In addition, my figures are based solely on clumps that exceeded Poisson predictions and on birds flying on tracks less than  $60^\circ$  apart.

My results also conflict with Lowery and Newman's in that they describe spring and fall migration to be fairly evenly random in spacing though "the fall flight may not be quite as consistently dispersed as flights in spring." In my data no significant differences were established between spring and fall. In addition, my estimates of the percent of flocking generally showed the spring to have higher levels of clumping than the fall. Lowery and Newman did not report significant night-to-night variation in flocking patterns while my spring data (10-sec units) suggest a correlation of the degree of flocking with the numbers of birds observed.

Gauthreaux (1972) made lunar observations that began before sunset and continued into darkness. He noted that the tight flocks of passerines he saw during the day yielded to a pattern of only single birds crossing the face of the moon after dark. Gauthreaux's study, though showing the breakup of tight diurnal flocks, may have failed to detect loose night groups because he did not examine the temporal order in which the birds were observed.

Bellrose (1971) made a unique visual study of nocturnal migration from a small airplane equipped with special lights that let him sample nocturnal migration over a wide geographic area. His airplane cruised at 120 MPH (53.6 meters per sec) and he



considered it unlikely that birds separated by intervals longer than 2 sec could be associated. Bellrose found that small birds migrate both singly and in groups. He noted that single birds appeared to predominate in the air space when the volume of migration was light, but when the volume ranged from moderate to heavy, groups of birds predominated. This observation is similar to my analysis of spring migration but close comparisons are impossible because Bellrose provided no quantitative data on spacing. His claim that groups predominate, suggesting more than 50% during moderate to heavy migration, should perhaps not be taken at face value if it is based solely on subjective impressions. My impressions were also that groups predominate during heavy migration but Poisson analysis rarely revealed levels exceeding 20%.

Radar studies of the grouping of nocturnal migrants have often been hampered by the inability of most radars to distinguish between flocks and single birds. Nisbet (1963) tried to overcome this problem with a mixed radar and moonwatching technique. He determined that for the fall migration radar echoes usually represented between 2 and 12 birds. After noting in particular that the average number of birds per echo increased only very slowly with the volume of migration, he concluded that many birds migrate in flocks. Eastwood and Rider (1966) studied nocturnal grouping in England using a narrow beam tracking radar and a wide beam surveillance radar. They believed that true groups would appear as discrete echoes on both units. Eastwood found that some birds seemed to be migrating in groups that remained together even when tracked a considerable distance, but that the majority eventually broke up, presumably because of differences in speed and heading among the component birds. Eastwood and Rider concluded that most of the groups observed by radar were an artifact of the pulse-volume effect and suggested that even some of the groups that continued together for extended periods were artifacts resulting from birds having taken off from a common locality.

Strict comparisons of radar studies with my data are difficult, but Eastwood and Rider's study provides results somewhat parallel to my own. The basic similarity in our work is the observation that although most nocturnal passerine migration consists of single birds randomly spaced, it is by no means exclusively so, and clumping is a regular occurrence. Eastwood and Rider's hypothesis that cohesive flocks might result from birds coincidentally taking off together and heading in the same direction does not, I think, explain very much of the grouping that occurs. If birds did take off together, even slight differences in velocity would soon space out individuals that were not trying to stay together. In addition, Hebrard (1971) and Cochran et al. (1967) noted that migration is generally initiated within the first two hours after dark, and thus any "roosting effect" would disappear early in the night. Yet my data showed no decrease in flocking in the later hours of the night.

Bruderer and Steidinger (1972) studied the dispersion of spring nocturnal migrants in Switzerland. They used a narrow beam tracking radar that could distinguish between single birds and flocks. They found that the nocturnal migrants were almost entirely singles while during the day flocks prevailed. They described the minimum distance between birds as 50 m with distances of 150 to 300 m being most frequent. In comparing their results from high and low volume migration, they noted that during light migration only a part of the distances between birds grow larger while a noticeable fraction remain the same, suggesting the existence of loose groups. They also found that the flock size increased with the density of migration. These results are similar to mine and Eastwood and Rider's in that the majority of passerines were

observed migrating singly, but small flocks were of regular occurrence. Their estimate of flock size is also similar to mine.

The flocked migrants that Bruderer and Steidinger reported generally maintained distances of 100 to 300 m. The majority of the clumped birds that I recorded occurred at time intervals that, when converted to distances, assuming ground speeds of 30 mph (13.4 mps), indicated much tighter flocks with distances usually less than 50 m.

The horizontal spacing of nocturnal passerine migrants has theoretical importance in terms of the mechanisms of orientation and navigation. If birds migrate in flocks, a potential exists for information exchange between individuals that might enhance navigation ability. Hamilton (1967) and Griffin (1969) discussed various possibilities. Many species of passerine migrants emit call notes during nocturnal flights and it has been hypothesized that these vocalizations serve to maintain flock organization (Hamilton 1967). My data indicate that flocks are of such infrequent occurrence as to necessitate a reevaluation of the role of calling by migrants and to render it less likely that coordinated groups of individuals are an important component of navigation.

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#### LITERATURE CITED

- ABLE, K. P., AND S. A. GAUTHREAUX. 1975. Quantification of nocturnal passerine migration with portable ceilometers. *Condor* 77: 92-96.
- BALL, S. C. 1952. Fall bird migration on the Gaspé Peninsula. *Peabody Mus. Nat. Hist. Bull.* 7.
- BELLROSE, F. C. 1971. The distribution of nocturnal migrants in the air space. *Auk* 88: 397-424.
- BRUDERER, B., AND P. STEIDINGER. 1972. Methods of quantitative and qualitative analysis of bird migration with a tracking radar. NASA SP-262, Animal orientation and navigation: 151-162.
- COCHRAN, W. W., G. G. MONTGOMERY, AND R. R. GRABER. 1967. Migratory flights of *Hylocichla* thrushes in spring: A radiotelemetry study. *Living Bird* 6: 213-225.
- DRURY, W. H., AND J. A. KEITH. 1962. Radar studies of songbird migration in eastern New England. *Ibis* 104: 449-489.
- EASTWOOD, E., AND G. S. RIDER. 1966. Grouping of nocturnal migrants. *Nature* 211: 1143-1146.
- GAUTHREAUX, S. A. 1969. A portable ceilometer technique for studying low-level nocturnal migration. *Bird-Banding* 40: 309-320.
- . 1972. Behavioral responses of migrating birds to daylight and darkness: A radar and direct visual study. *Wilson Bull.* 84: 136-148.
- GRIFFIN, D. R. 1969. The physiology and geophysics of bird navigation. *Quart. Rev. Biol.* 44: 255-276.
- HAMILTON, W. J., III. 1962. Evidence concerning the function of nocturnal call notes of migrating birds. *Condor* 64: 390-401.
- . 1967. Social aspects of bird orientation mechanisms. Pp. 57-72 *in* Animal orientation and navigation (R. M. Storm, Ed.). Corvallis, Oregon State Univ. Press.
- HEBRARD, J. J. 1971. The nightly initiation of passerine migration in spring: A direct visual study. *Ibis*: 8-18.
- HEPPNER, F. H. 1974. Avian flight formations. *Bird-Banding* 45: 160-169.
- LOWERY, G. H., AND R. J. NEWMAN. 1955. Direct studies of nocturnal bird migration. Pp. 238-263 *in* Recent studies in avian biology (A. Wolfson, Ed.). Urbana, Univ. Illinois Press.
- NISBET, I. C. T. 1963. Quantitative study of migration with 23-centimeter radar. *Ibis* 105: 435-450.
- POOLE, R. W. 1974. An introduction to quantitative ecology. New York, McGraw-Hill Co.
- SOKAL, R. R., AND F. J. ROHLF. 1969. *Biometry*. San Francisco, W. H. Freeman Co.
- STONE, W. 1906. Some light on night migration. *Auk* 23: 249-252.