A RADAR STUDY OF THE ALTITUDE OF NOCTURNAL PASSERINE MIGRATION

By Kenneth P. Able

INTRODUCTION

On long-range radar, the diffuse, grainy echo pattern produced by passerine nocturnal migrants frequently causes saturation of the radar scopes (PPI, RHI) up to 25 nautical miles. The development of a means of quantifying nocturnal migration on the weather surveillance radar (Gauthreaux, 1970) permits the collection of quantitative data on the altitudinal distribution of the passerine migrant swarm. The results I have obtained with this technique suggest that passerine nocturnal migrants fly at altitudes much lower than those reported in most of the previous radar studies.

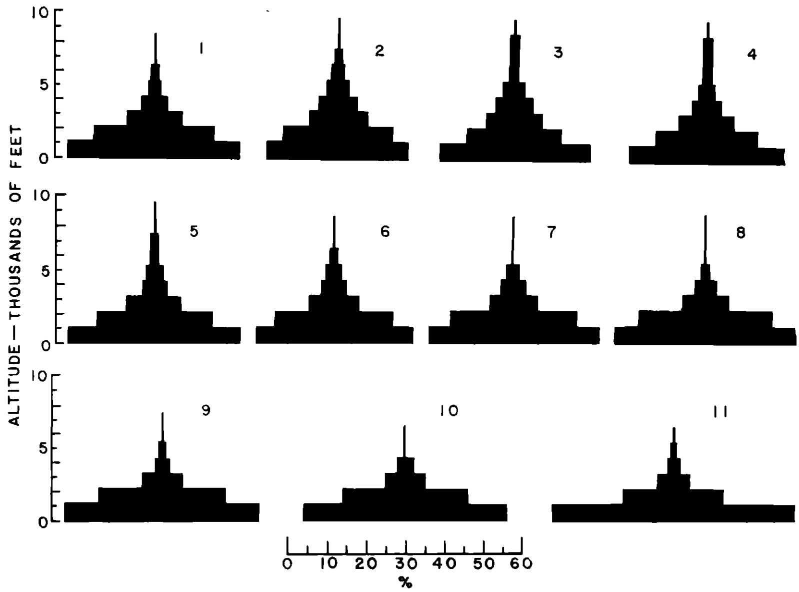
METHODS

I conducted this study on 20 nights in September and October, 1969, using the WSR-57 radar at the Lake Charles Weather Bureau in southwestern Louisiana. The station is at the Municipal Airport, about 23 nautical miles north of the coast. Gauthreaux (1970) discussed the pertinent characteristics of the WSR-57 and the method for quantifying nocturnal migration from its PPI. At one-hour intervals during the night I determined the quantity of passerine birds in the radar beam at one degree intervals of antenna elevation. The readings were made at a range of 9-11 nautical miles in areas where there was no interference from ground echoes. The array of dot echoes above the fine passerine echoes was not sampled. These higher, fast-moving echoes were probably produced by flocks of shore birds and waterfowl.

At 10 nautical miles, the vertical beam width of the WSR-57 is about 2,120 ft. Elevating the radar antenna 1° raises the axis of the beam 1,060 ft. Thus there is no appreciable overlap in samples taken at alternate degrees (0, 2, 4 . . .). Due to the pulse-volume effect, it is impossible to determine where in the spread of the beam a particular echo-producing bird is located. Thus, a heavier density of birds in the lower half of the beam would result in a slight overestimation of height. Sampling at 1° intervals reduces this bias by increasing the altitudinal resolution to between 1,060 and 2,120 ft. More precise measurements can be obtained with short-pulse, vertical-beam radars, but greater resolution is not essential for my purposes.

All weather data were collected at the Lake Charles Weather Bureau. I have expressed cloud amounts on a scale from 0 to 10, where 0 indicates clear, 10 complete overcast. For purposes of analysis, I have treated 0-5 conditions as "clear" and 6-10 as "overcast." There were only three nights with three or more consecutive hours of overcast during the collection of the data (see Figure 4 for dates and specific cloud amounts).

Figure 1. The altitudinal distribution of passerine echoes under clear skies for 11 successive hours after sunset. All hours during the 20-night study with clear skies are combined. The ordinate of the histograms is equal to the percent of birds in each altitudinal stratum, measured at a range of 10 nautical miles.

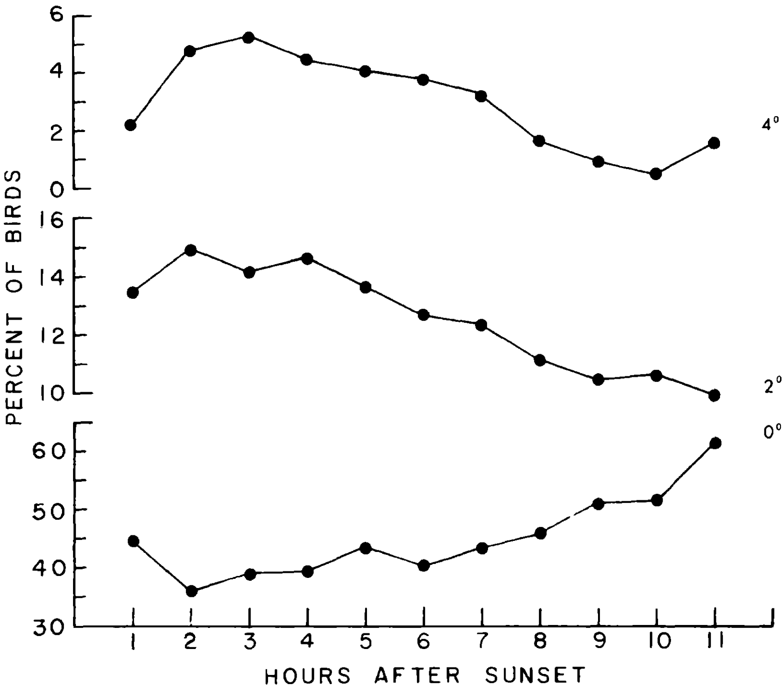


RESULTS

Nightly altitudinal distribution.—Figure 1 shows the altitudinal distribution of passerine echoes for 11 successive hours after sunset. All hours with clear skies are combined. The sample from the first hour, when most of the nocturnal exodus takes place, shows migrants heavily concentrated (75.6%) in strata below about 2,500 ft. During the second hour after sunset, dispersal of some birds to higher altitudes gave rise to a higher mean height, and the percentage of birds below 2,500 ft. was 63.9. Following the second hour (*ca.* 20:00), there was a gradual decrease in mean altitude for the remainder of the night. During the ninth, tenth, and eleventh hours after sunset, 83.9, 83.5, and 86.5% of the birds, respectively, were below 2,500 ft. An expected sharp fall in migration traffic rate (Lowery, 1951; Newman, 1956) accompanied the decline in altitude. Thus there were progressively fewer birds in the air during the later hours of the night.

In Figure 2 the data are plotted to illustrate the change in the quantity of migration for three selected altitudinal zones. The sharp drop in the percentage of birds in the 0° sample during the first hour indicates that birds were climbing rapidly. This trend is clear despite the continued departure of large numbers of birds

Figure 2. The percent distribution of passerine echoes at three non-overlapping sample altitudes for 11 successive hours after sunset to show the hourly changes in the numbers of birds at each of these altitudes: 0° = 0-1, 440 ft.; 2° = 1,440-3,560 ft.; 4° = 3,560-5,680 ft.

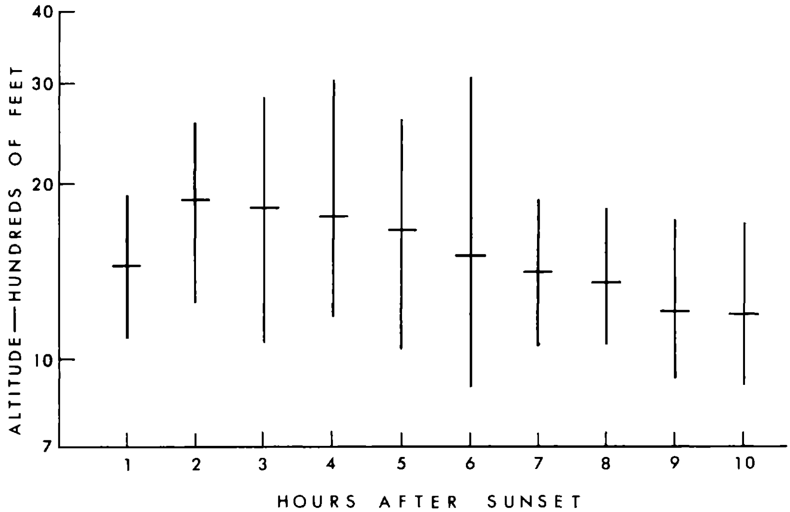


during that hour (Gauthreaux, 1968). Simultaneously, marked percentage increases occurred at higher (2° and 4°) sampling levels. This further indicates that the birds climb rapidly after take-off. The curves also show the decline in numbers at 2° and 4° three to four hours after sunset. These declines are accompanied by a continual *percent* increase at the lowest level (0-1,440 ft.) until the hours near dawn, when the sample becomes contaminated by local movements of non-migrants.

The hourly mean altitudes for all combined clear nights are plotted in Figure 3. Each of the *combined means for a given hour* is below 1,900 ft. The highest *mean for a single hour* I recorded during this study was 3,037 ft. at 22:00 on 17 September. Some passerine echoes were seen at antenna elevations of 7° (6,740-8,860 ft.) on 20% of the nights sampled, and at 8° (7,800-9,920 ft.) on 10% of the nights. The maximum altitude at which I recorded passerine echoes during the study was 8,860-10,980 ft. (9°) at 21:00 on 18 September.

Altitude and winds aloft.—I compared the mean altitude of passerine migration at the sixth hour (*ca.* 24:00) on 13 clear nights

Figure 3. Mean altitudes and ranges of passerine nocturnal migration for 10 successive hours after sunset. All hours with clear skies are combined. Horizontal lines are the means; vertical lines show observed ranges of the nightly means.

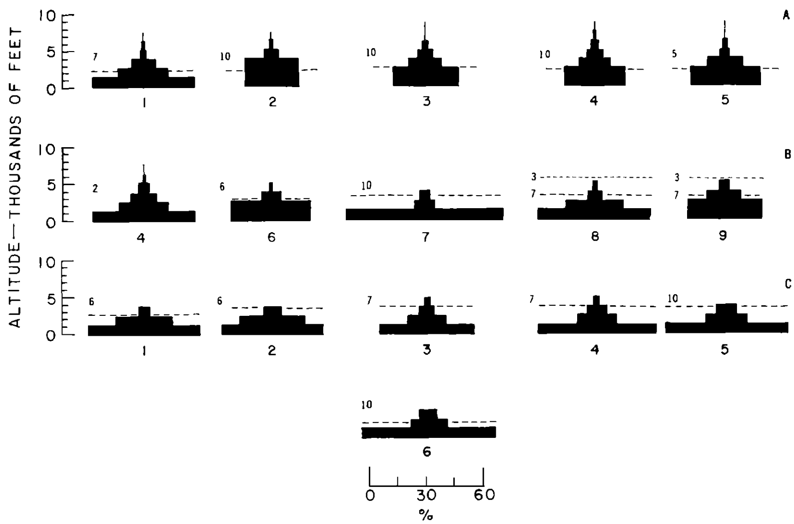


with wind velocity at midnight at 2,000 ft. Although wind speeds ranged from 12-30 knots at the mean altitude of migration on these nights, a significant negative correlation ($r = -.750$; $p < .01$) was found. Thus it appears that wind velocity directly influences migration altitude. Since flight directions were downwind on each night of the study, I compared the altitudes of migration on nights when the movements were "northward" with nights when they were "southward." I found no significant difference ($p > .10$).

Altitude and overcast.—Figure 4 illustrates the altitudinal distribution of migrants on three nights with several hours of heavy overcast. A comparison of these patterns with those for the same hours on clear nights (Figure 1) shows that under overcast there is a marked compression of birds into the area below the cloud deck. It appears that birds attempted to fly below the overcast on these nights. On no occasion do my data indicate that birds attempted to increase their altitude in an effort to fly above the clouds.

Comparisons of bird altitude with cloud height are hampered by the imprecise nature of available cloud measurements. For example, a cloud condition of "10" may result from several layers of incomplete overcast at different altitudes. No information is available on the thickness of cloud cover. However, on the night of 7-8 October it appears that some birds may have been flying within or above the cloud deck. Due to the limitations of radar methods (see Discussion) it is impossible to make such a statement with certainty.

Figure 4. The altitudinal distribution of passerine echoes on three nights with overcast skies. (A) 7-8 October; (B) 9-10 October; (C) 12-13 October. Hours after sunset are indicated below each figure. Cloud amounts are shown at the left of each figure, and the altitude of the bottom of the cloud deck is indicated by the broken line.



Altitude and size of the migration.—On any given clear night, my data suggest a positive correlation between the mean altitude at the middle of the night and the maximum migration density ($r = .697$; $p < .01$). On the night of 17-18 September I recorded a maximum radar density equivalent to a migration traffic rate of 25,000 birds per mile of front hour $^{-1}$. About midnight the mean altitude was 2,600 ft. On the night of 2-3 October, the maximum density was equivalent to a traffic rate of 800 birds per mile of front hour $^{-1}$ and the mean altitude was 1,000 ft. These two instances represent the extremes in terms of bird density correlated with midnight mean height.

Systematic data were not collected over a sufficient period of time to permit an analysis of the seasonal pattern of altitudinal distribution. However, observations made in August, early September and late October suggested that migrations later in the season tended to occur at lower altitudes.

DISCUSSION

My data indicate that the bulk of birds migrate at considerably lower levels than do most published estimates. The radars used by Bellrose and Graber (1963) and by Lack (1960) were unable to detect birds at the lower altitudes, and Nisbet (1963) based his measurements on conspicuous flock echoes above 600 ft. Lack (1960) was unable to determine a mean or most frequent altitude in autumn because of the mass of passerine echoes at low altitudes. He concluded that most nocturnal migrants crossing the North Sea in autumn did so at altitudes below 5,000 ft. In spring he found that most echoes were located between 2,000 and 5,000 ft. during the first part of the night. Due to the characteristics of their radar, Bellrose and Graber (1963) were unable to detect most birds below 1,500 ft., and their data were probably biased to a lesser degree at even higher altitudes. This being the case, my results suggest that they were usually missing over half of the passerine migrants in the air. Their results indicate that the most frequent altitude in spring was about 2,000-3,000 ft., and that autumn migration averaged slightly higher. My data on the absolute altitude at which passerine migration takes place differ markedly from these estimates. My hourly means for clear nights are all below 1,900 ft. For every hour of the night, more than 60% of the passerine migrants were below 2,500 ft. I believe in general that limitations in equipment and sampling methods are responsible for the earlier overestimation of the altitude of land bird migration.

My results agree generally with Nisbet's (1963) in that nightly mean altitudes were usually between 1,500 and 2,500 ft. About 90% of the birds were below 5,000 ft., and only about 1% were above 10,000 ft. Nisbet concentrated on discrete dot echoes above 600 ft. and collected his data over the Atlantic Ocean. Thus our results are not strictly comparable. Likewise, my results agree, in general, with those of Eastwood and Rider (1965) concerning the altitudes at which most nocturnal migration takes place. They observed low birds within 500 ft. of the ground. Gauthreaux (1968) measured altitudes in spring with the same equipment I used, and my results for autumn are nearly identical to his.

The correlation between flight altitude and wind speed suggests that wind velocity, alone, or in combination with some other factor, influences the altitude of nocturnal migration. The range of wind speeds at altitudes where migratory flights take place was too great to support the idea that migrants select wind speed with precision as proposed by Bellrose (1967: 293-294). High wind speeds are a potential danger to the migrating land bird in terms of displacement. Therefore, it is advantageous, on the average, for birds to attempt to avoid high winds, and this can often be accomplished by flying at lower altitudes. Avoidance of high wind velocities by migrating at lower altitudes, rather than selection of particular wind speeds, is a possible explanation for both the negative correlation between wind velocity and bird altitude and the wide range of wind speeds in which the birds fly.

The behavior of nocturnal migrants in the presence of overcast is of considerable interest in terms of proposed mechanisms of celestial orientation. Several workers (Bellrose and Graber, 1963; Bellrose, 1967; Eastwood and Rider, 1965) have reported numbers of birds flying within clouds. Considerable caution must be taken in making such assertions from radar data. The rapid increase in the size of radar resolution cells with distance can cause birds immediately above or below clouds to appear to be within the overcast layer. For this reason, a histogram of bird height could show an even distribution of birds through an altitudinal stratum with overcast when few or none are actually in the clouds, provided the cloud deck is comparatively thin. On 7-8 October (Figure 4A), my data indicate that birds may have been within clouds, the exact number depending upon the thickness of the overcast. Unfortunately, no information is available on the thickness of the cloud layers over Lake Charles, and I am not prepared to state certainly that the birds I recorded were actually within the clouds.

Attempts to determine the manner in which overcast influences the flight behavior of migrants aloft have yielded inconsistent results. Bellrose and Graber (1963) stated that migration tends to take place at higher altitudes on overcast nights and that this is caused by an attempt on the part of individual migrants to climb above the clouds. Eastwood and Rider (1965) reached a similar conclusion. Bellrose (1967) later amended his view and pointed out that this behavior occurs only when low layers of clouds *also* have low tops. I found no such behavior with low overcast, but I have no information on the altitude of the cloud tops on these nights. The instances of overcast I observed resulted in considerably lower flight levels than at the same hours on clear nights. Most migrants adjusted their altitude to fly below the clouds. The advantages of this behavior are obvious—to maintain visual contact with the ground.

The hour-to-hour variation in the altitudinal distribution of nocturnal migrants is only poorly documented. Eastwood and Rider (1965) measured heights of spring and fall migrants over southeastern England at six-hour intervals. These data give only a crude index of the behavior of the birds, but a pre-midnight peak was indicated, followed by a decrease until dawn. Nisbet (1963) estimated altitudes at 20:00, 22:00, and 24:00 EST. Unfortunately, no allowance was made for the changing time of sunset and the concomitant change in the onset of nocturnal migration. Nevertheless, his peak altitude around 22:00 EST corresponds roughly to my peak in the second hour after sunset (*ca.* 21:00 CST). Thus, my temporal pattern of altitudinal distribution agrees basically with that derived from other studies.

The hourly measurements taken in this study clearly document the steep climb made by migrants during the first hour of migration. The gentler slope of the falling altitudinal curves later in the night suggests that a gradual lowering of the migrant population occurs during these hours. However, the declining altitudes occur during a time when migration traffic rate drops rapidly (Newman, 1956; Gauthreaux, 1969; in press). A decreasing traffic rate implies that birds are being continually removed from the migrant population aloft. This decrease in the number of birds will cause a reduction in the range of altitudes represented in a sample and an apparent lowering in the altitude of the migration. If a migrant's probability of landing during the pre-dawn hours is independent of the altitude at which it is flying, an inspection of frequency polygons for this period of falling traffic rates would suggest a decrease in altitude whether or not this was actually the case. A reduction in bird density will not, however, alter the mean of the skewed altitude distributions. Thus, the falling density coupled with the lowering of the mean altitude during the pre-dawn hours clearly indicates (1) that migrants are continually landing, and (2) that the mean altitude of those birds remaining aloft falls gradually to a point about 600 ft. lower than the peak mean for the night.

The problem of landing by nocturnal migrants during darkness has been discussed by a number of workers. Visual observations of landing at night by nocturnal migrants have been made by Hebrard (1969). Cochran, *et al.* (1967) recorded landing at night by thrushes carrying telemetry devices. My own observations and those of Gauthreaux (1969) with a portable ceilometer have confirmed that large numbers of passerines do not continue to migrate at lower altitides during the late hours of the night.

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SUMMARY

The fall nocturnal migration of passerine birds on the northern Gulf coast takes place at relatively low altitudes, with over 90% of the birds almost always below 5,000 ft., and over 75% below 3,000 ft. In all cases, the altitudinal distributions assumed a pyramidal shape with the greatest number of birds in the lowest strata (within 1,250 ft. of the ground). Very small numbers of passerine-type echoes were occasionally recorded as high as 8,860 to 10,980 ft.

Following the nocturnal exodus shortly after sunset, migrants climb rapidly, and most birds reach the maximum altitude for their night's flight during the first hour of migration. The nightly peak mean altitude was recorded at the second hour after sunset and the height distribution of the migrant swarm fell gradually

during the remainder of the night. The decreasing mean altitude caused by the lowering of birds remaining aloft was accompanied by falling migration traffic rates produced by the landing of migrants during the pre-dawn hours.

Mean altitude was found to be negatively correlated with wind speed, although a wide range (12-30 knots) of wind velocities characterized the mean altitude on various nights. Migrants were compressed into lower altitudinal strata under solid overcast and no attempt to surmount the clouds was made. Mean altitudes were positively correlated with the size of a night's migration.

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