AN AUDIO TECHNIQUE FOR THE STUDY OF NOCTURNAL MIGRATION OF BIRDS

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THE long-standing interest of ornithologists in nocturnal migration has, if anything, increased in recent years with the perfection of techniques for direct study of the phenomenon.

As early as 1880, Scott (1881) pointed out the potential value of lunar observations in the study of migration, and subsequently many workers have utilized the technique (see Carpenter, 1906; Lowery, 1951, for history and bibliography). Howell, Laskey, and Tanner (1954), and others have studied migration in the light of ceilometer beams.

Radar is a very promising tool (Sutter, 1957*a*, 1957*b*), and its use for study of migration is still in a development stage.

A technique which has been used almost as widely as that of lunar observation is the audio method based on detection of flight calls (Libby, 1899; Kopman, 1904; Tyler, 1916; Ball, 1952; and others).

Recently, Lowery and Newman (1955) summarized current knowledge on the subject of direct observation of nocturnal migration. These authors applauded the work of Ball (1952) but pointed out the basic limitations of the audio technique which he used. There are three principal shortcomings of the technique as used by Ball and others: (1) With the unaided ear, migrants can be heard only when they are flying low. Ball (1952:49) calculated that he could detect calls of *Hylocichla* thrushes to a maximum elevation of 1500 feet, but migrants may fly well above this range. Miller (1957) reported on a sparrow (*Zonotrichia*) migrating at 10,000 feet. (2) The unaided ear does not provide precise directional coverage of a measurable area of sky. (3) Variability in human hearing tends to invalidate comparative quantitative studies by different observers.

When these problems are solved it becomes possible to calculate the number of calls of migrants per unit of area of sky (flight-call density). The relationship of this quantity to true density of migrants is an unknown, but the solution of this larger problem depends first upon the perfection of the audio technique and then upon correlation of audio and visual methods. If the ratio of flight calls to observed birds is found to follow a definite pattern, then the audio technique will be useful for quantitative studies. In any case, the two methods complement each other, the visual method providing more precise quantitative data, the audio method qualitative.

We became interested in these problems while making observations on nocturnal migration in the spring, 1957. Using standard equipment which has found application in a variety of fields, we experimented and developed a promising method for detecting and recording migration.

It is the primary purpose of this paper to present detailed information on the technique and its development, and on the results of our tests with the equipment.

The technique was used to record migration in central Illinois in the fall of 1957, and in the spring and fall of 1958. Data from this nearly continuous record will be presented in another paper, but in order to show the potentialities of the audio method, we have included in the present paper graphs on five nights of migration, representing three seasons, along with a brief discussion of the data.

Acknowledgments

A number of people helped us in the development of the technique and in the pursuit of our studies on migration. We especially wish to express our appreciation to Frank Bellrose and other members of the staff of the Illinois Natural History Survey for encouragement and advice. Glenn Poor contributed substantially in the construction and maintenance of equipment, and particularly with the development of the timing device for the recorder. Jack Ellis and Ronald Labisky helped with the establishment of two of our study stations.

William G. Albright and George W. Swenson of the University of Illinois Electrical Engineering Department gave us valuable advice on the use of electrical equipment and loaned us equipment for making tests. Members of the staff of the University Antenna Research Laboratory kindly loaned us two large parabolic reflectors which were essential to the work. The University Physics Department also loaned us equipment for testing. Glenn E. Stout and other members of the Meteorology Section of the Illinois State Water Survey provided us with weather data. Tom N. Morgan and Jean W. Graber helped us with a number of engineering and ornithological problems.

Barney McMullin of Seymour, Illinois, kindly permitted us to establish an audio station on his property and donated electric power and shelter for our equipment.

Equipment and Method

Heretofore, workers studying migration with the audio method have depended on the unaided ear to detect the calls of migrating birds. Our method employs equipment (Fig. 1) which is basically the same as that used by several workers to record songs of birds. Radio broadcasters have also used parabolic reflectors or horns with their microphones for many years in order to pick up distant sounds. Thus, our only problem was to test and adapt already existing techniques to the particular problems of flight-call detection of nocturnal migrants. As one of our aims is to provide a relatively inexpensive, duplicable system employing readily available parts and equipment, we have made no attempt to approach the ultimate in detection equipment.

The essential items of equipment are: a sound gathering device (parabolic reflector or horn), a microphone, an amplifier, and a recorder. The parabolic reflector gathers sound over a large area (the aperture area of the parabola) and reflects it to a point (the focus) where a microphone or speaker is located. The microphone converts the variations in air pressure (sound) into variations in voltage at its terminals. These voltage variations are in turn amplified by the audio amplifiers and finally fed to the recording head of a recorder and recorded on tape.

FIG. 1. Equipment used for flight-call detection of nocturnal migrants. From left: recorder, recorder timer, high-pass filter; parabolic reflector surrounded by straw sound baffle, and pre-amplifier with speaker (black box).

Because sound intensity varies inversely as the square of the distance, whereas the amount of sound picked up by a parabolic reflector varies directly as the square of the reflector's diameter, it is a rule of thumb that the maximum distance of detection will vary directly as the diameter of the parabola. Actually, doubling the diameter of a parabola may more than double the maximum distance of sound detection because the additional directivity obtained from the larger parabola will reduce the level of external interfering noise. Maximum range depends on four factors, three of which are in the category of equipment. These are: (1) the size of the parabola, (2) the sensitivity of the microphone, and (3) the sensitivity of the amplifier. The fourth factor, external noise, will in most cases be the limiting factor.

We used a large parabolic reflector (diameter, 72½ inches; maximum depth, 14¼ inches; and focal point, 19 inches), but a logarithmic-base horn might work as well and would probably be less expensive than the reflector.

To pick up sound gathered by the parabola we first tried several crystal microphones, all of which were satisfactory though with some variation in performance. Because crystal microphones deteriorate when exposed to the heat of the sun or to high humidity, we tried an inexpensive 4-inch permanent magnet (pm) speaker with a voice-coil-to-grid matching transformer. The speaker proved to be at least equal in performance to the crystal microphones, and with a thin coating of plastic spray over the cone it has withstood the weather through two seasons of operation.

Most tape recorders have a self-contained amplifier, but for this technique a pre-amplifier which provides additional amplification and a lower noise (internal hiss) level is essential. Many of the high fidelity pre-amplifiers on the market would be satisfactory with very little adaptation, but we obtained excellent results with a relatively inexpensive, simple amplifier which we made for this application. (See Fig. 2 for details of the electrical system.)

The speaker and amplifier were housed in a small metal box (4 × 5 × 6 inches), and the box was made weatherproof with gasket material, gasket seal, and copious quantities of paint.

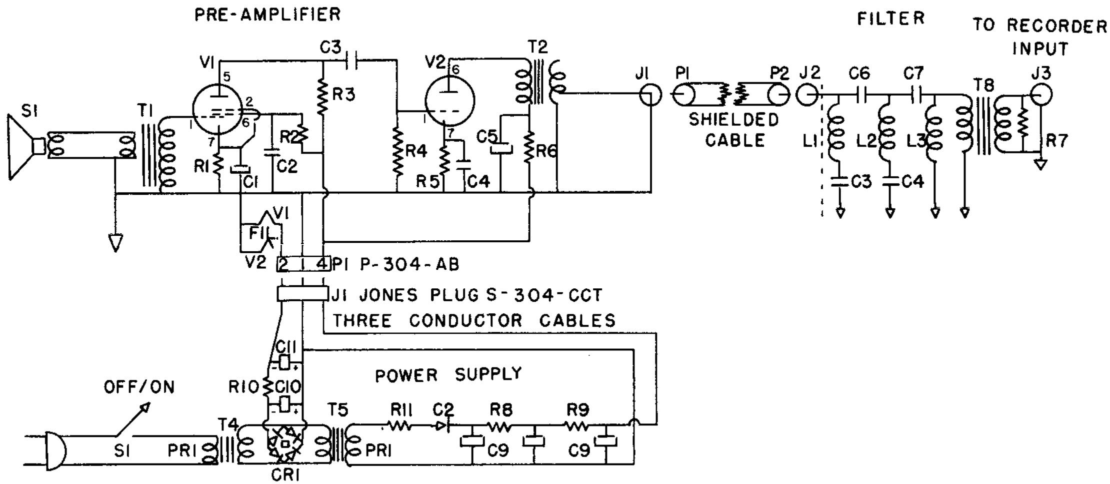
The amplifier box was clamped on a half-inch steel rod extending from the center of the parabola so that the open speaker end of the box was located at the parabola's focal point.

Sockets were provided on the amplifier box for power plug and output connection. Power for the pre-amplifier may be from batteries or from a power supply operating on 110 volts a.c. Initially, we used a 6-volt storage battery and a 90-volt dry cell to power the amplifier. Drain from the dry cell is so small (1.5 ma) that it will last almost shelf life, but the storage battery must be recharged after each 30–40 hours of operation. Our station now uses a power supply operating on 110 volts a.c. (See Fig. 2 for details.)

The output of the pre-amplifier may be fed directly into a pair of headphones to establish a listening post to study the sounds of nocturnal migration. If battery-powered, the equipment is portable, and, with a parabola mounted on truck or car, an investigator can check on migration at widely scattered locations during a single night.

With a fixed station, the output of the pre-amplifier can be carried over a considerable distance through shielded cable to a tape recorder located well away from the reflector in some permanent shelter.

In attempting to record sounds of migration we encountered numerous interfering sounds, many of which were of frequencies below 350 cycles per second. The inclusion of an appropriate high-pass filter (see Fig. 2) between the output of the pre-amplifier and the input of the recorder greatly attenuated frequencies below 350 cycles and improved considerably the range of the equipment without affecting reception of most bird calls.



SI- 4" pm speaker 3.2Ω v.c. P-950-4 OXFORD
RI-IOK IW.
R2-3 9 meg. aerovox CP-1/2 carbonfilm
R3-.5 meg. aerovox CP-1/2
R4-I meg. aerovox CP-1/2
R5-2500Ω IW.
R6-20K IW.
CI-25 mF 25V. electrolytic
C2-.I mF 600V.
C3-.00I mF 600 V.
C4-.25 mF 400V.
C5-16 mF 450V. electrolytic
VI-6AV.5
V2-6C4

TI-Merit A-2923
T2-Thordarson 22S59
J2-female jack

T4,T5-Thordarson 26F67
PRI 117 vac sec 126V 2A
C9 - triple section 40/40/40 yf, 150 V.D.C. wkg. electrolytic.
R8,R9 - 20K IW.
CIO,CII- Cornell Dubilier 1000 I 1000 yf, 15 V.D.C. wkg.
RIO - 10Ω 2W.
CR I- Sarkes Tarzian D-17 selenium full wave bridgerectifier

CR 2- Federal 1389 65 m.a. selenium rectifier
SI - toggle switch spst
R II- 50Ω, IW.

R7 - 120 K 1/2 W.
T3 - Thordarson 20A34 transformer 500Ω/100K
LI,L2-Thordarson T-20C58 choke 0.75 hy
L3 - J.W. Miller 6324 60-130 mhy, adjustable
C6,C7,C8,C4 - .5 mF 400V.

FIG. 2. Diagram of electrical equipment, pre-amplifier, filter, and power supply, used in audio technique.

Without a tape recorder, the investigator must be in constant attendance while data are being recorded. The addition of a tape recorder to the system permits the recording of migration without a full-time operator and provides a record which can be read and reread at the investigator's convenience. Furthermore, if more than one set of apparatus is available it becomes possible to make simultaneous "observations" at two or more localities.

In our work we used a standard model tape recorder (Revere T 10) with 7½-inch reels. Most standard recorders have recording speeds of 7½ inches and 3¾ inches per second. Even at the slower speed 2400 feet of tape will last less than two hours.

To obtain a nightly 8-hour record of migration during the fall of 1957, we altered the gear ratio of our recorder so that it ran tape at the rate of about two inches per second, and used specially made 14-inch aluminum reels that would carry over 6000 feet of 1½ mil audiotape. With the combination of slow recorder speed and large quantity of tape we could record continuously for over eight hours. To carry these large reels we had bicycle axles mounted on each side of the recorder at the level of the turntable. Several problems were involved in handling this amount of tape. Slowing the recorder speed reduced the fidelity of the recording, especially of high frequency sounds. Such heavy reels tended to burden the recorder and occasionally caused the machine to fail. The greatest drawback in the system was the vast amount of time required to collect the data. Each 8-hour record on tape required eight hours or more to audit. Timing the nightly migration involved correlating the start of recording time with the start of auditing time. Reading the tape was especially tedious for periods when there was little migration.

To remedy these problems we altered our equipment by inserting an automatic, intermittent timer in the circuit of the recorder. Glenn Poor of the Illinois Natural History Survey adapted an ordinary, furnace, stoker-hold, fire timer to open and close only the circuit of the reel-turning motor of our recorder. In operation the amplifier circuit of the recorder remains activated continuously. The timer may be wired to the recorder or arranged with a plug-in. It can be adjusted to obtain any length of recording sample at intervals as short as a few minutes or as long as an hour. Our device is set to take samples of 1½ minutes duration at 10-minute intervals. A maximum total sample of about 2–2½ hours may be recorded on a standard 7½-inch reel at a recording speed of 3¾ inches per second. For a larger sample, the investigator must either slow the recorder or make special reels to handle more tape.

When the timer initiates the recorder motor, a characteristic sound is recorded on the tape. Because these sounds come at regularly spaced, precisely timed, intervals, they facilitate the timing of migration during the night.

INTERFERING SOUNDS AND EQUIPMENT LOCATION

In using a high-gain amplifier system to study migration, the proper location of the equipment is very important. As the relatively weak signal of a bird call is amplified, so also are the sounds from outside sources—trains, highways, wind, livestock, etc.

There is no substitute for a good, quiet location, but filters in the electrical system (see above) can eliminate some of these extraneous sounds. If the investigator is interested in only one or a few species, filters could be used to eliminate virtually all sounds but those in the frequency range of the species being studied.

It is difficult to obtain good recordings of migration in an urban situation, though we did have some success with our equipment placed on top of the Natural Resources Building on the University of Illinois campus. For best results the equipment should be stationed in the country at least two miles from a railroad or major highway. We have found farmers to be most cooperative in permitting us to set up stations on their land. The cost of the electricity used by our equipment is almost negligible.

In any location, sound baffling around the parabola is essential. We used straw bales stacked three-high around the reflector, and found this to be an effective, durable baffle for a permanent station.

Some interfering sounds inevitably get through, or over, the baffle. Most of these are recognizable, but an occasional noise may cause confusion when the tape is read. Nonmigrating birds are a minor nuisance during the night. Many of our tapes have recorded owl calls, and a few have recorded songs of passerines. Relatively few migrants sing full songs in flight, though we have records for some species. It is usually possible to determine from the tape whether a singing bird is moving or stationary. In contrast to the lunar observation method, the present method can be used under a broad variety of weather conditions. Heavy winds (15–20 mph) interfere somewhat, and even moderate rains interfere completely because of the noise of raindrops striking the metal reflector. We have heard migrants during light rains, though the range of coverage is greatly reduced under these conditions. During the fall of 1957, not one of our nightly records was completely lost because of interfering sounds.

RANGE AND PERFORMANCE OF THE EQUIPMENT

We could not determine the vertical range (above the earth's surface) of our equipment, though we did obtain an accurate estimate of its range with tests conducted on a horizontal plane.

For the tests, we chose a site which offered an uninterrupted view (except for scattered trees and farm houses) of three miles. The area was flat except for a slight rise at one edge on which we located the reflector. We placed the parabola on edge and baffled it with straw bales at the back and sides. Tests were made on three nights offering a variety of wind conditions.

To check on range and sensitivity of our apparatus we used as a sound source a mechanical noisemaker which emitted a frequency of 2500 cycles per second and which could be heard by the unaided ear at a distance of 1512 feet. By comparison, the call notes of individual House Sparrows (*Passer domesticus*) were audible by the unaided ear to a distance of approximately 1240 feet. In loudness, then, our noisemaker is more nearly comparable to the call notes of *Hylocichla* thrushes as calculated by Ball (1952:49).

In our tests, one person moved straight out from the face of the parabola, signalling at irregular intervals with the noisemaker only. A second person, the auditor, remained at the recorder listening for the signal. From his position at the recorder the auditor acknowledged reception of the sound by signalling with a flashlight. From the distribution of positive tests we plotted the range of the equipment.

Under favorable conditions, with no surface winds, the maximum range of clear detection of the sound signal was 11,400 feet or approximately 2.2 miles. Most flights of nocturnal migrants probably occur well below this height (Lowery, 1951:389).

Heavy winds reduced the range considerably. Tests made on a night when cross winds were 15 to 18 mph indicated a maximum range of 3500 feet.

The true vertical range of our equipment may be greater than the tests indicate. With the parabola in its normal position of vertical coverage, background noises would undoubtedly be less with the same wind conditions than they were in our tests, because wind noise results principally from the action of wind upon objects on the earth's surface. With the baffle that we used, the limits of coverage were sharply defined though, obviously, maximum sensitivity is obtained when the signal is emitted directly over the parabola.

The directional pattern of a parabolic reflector may be computed approximately by formulas (Williams, 1950:147–157). The theoretical pattern of our reflector for a frequency of 2500 cycles is shown in Fig. 3. On paper, the pattern can be represented in two dimensions only, although it is actually three-dimensional, having a shape somewhat like a cigar. The angle of coverage is approximately five degrees with a maximum width of 900–920 feet, at a distance of 8000 feet from the parabola.

Obviously, a broader space is covered, at the higher levels (6000–10,000 feet), and an individual bird would be in range of the parabola longer at these levels. Quantitatively, the significant figure is the number of birds crossing a given line on the earth's surface.

The directional pattern of a parabola varies with the vibration frequency and intensity of the signal. Thus, loud calls of waterfowl would be detectable well beyond the range given for our tests, and, in calculating "flight-call density," these factors must be considered. The frequency range of the equipment (with filter) is from 350–5000 cycles per second using a recorder speed of 3¾ inches per second.

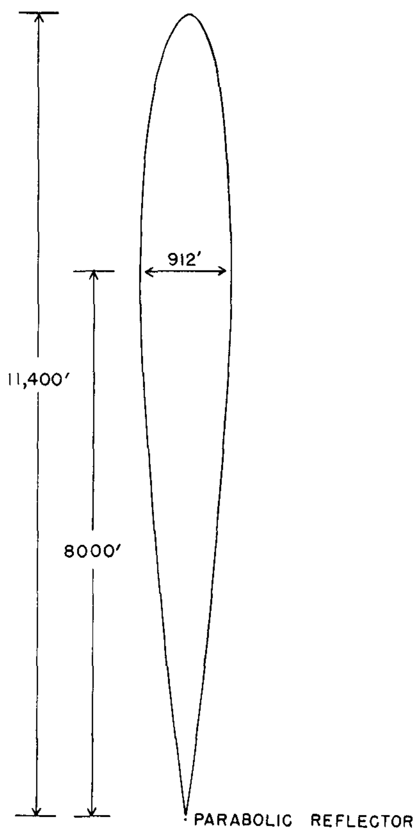


FIG. 3. Theoretical directional pattern of a 72-inch diameter parabolic reflector for a frequency of 2500 cycles per second or wavelength of 5.3 inches. The maximum range of detection of calls comparable in frequency and loudness to those of the *Hylocichla* thrushes is 11,400 feet. The maximum diameter covered is 912 feet at a distance of 8000 feet from the parabola.

Collection of Data and Sample Results

We have found the equipment described above to be very helpful in studies on nocturnal migration in the prairie region of east-central Illinois. With a semipermanent station, a nightly record of migration can be obtained with an expenditure of two to four hours per day, depending upon the location of the station and the length of the recording sample. The tape-recording must be started each evening, and the tapes retrieved and audited on the following day.

In transcribing data from the tapes we have phoneticized all call notes and, whenever possible, identified individual call notes. The time of calling was also noted in each case. From these basic data the accompanying graphs (Figs. 4–8) were constructed.

Though the audio technique in its present form is intended to complement direct visual studies, it can provide information on certain aspects of migration even without visual study.

The following discussions are based on the graphs and consider four general problems in which audio records may be helpful: (1) the hours of nocturnal migration and of calling by nocturnal migrants, (2) flight-call density, (3) the kinds of calls of nocturnal migrants, and (4) the conditions under which migration occurs.

Hours of Nocturnal Migration and Calling of Migrants

Data from visual and audio studies have been contradictory as to the hours of the night when migration occurs. From lunar observations at many localities, Lowery (1951:415–416) determined that maximum densities of migrants occurred before 1 a.m., with peak numbers coming between 10 p.m. and 1 a.m. Using an audio method in Gaspé, Ball (1952:55) found that there were two peaks during the night, one before 10 p.m. and a second between 3:30 a.m. and dawn.

Our recordings (for 125 nights) show only one *consistent* pattern. In central Illinois, migration may be detected at any hour during the night from sundown to sunup, but if migration continues until dawn there is often a marked increase in calling by migrants in the predawn hours. This peak depends at least upon the species of migrants involved and the factors which affect the intensity of dawn light. Increased calling at this time is particularly characteristic of the *Hylocichla* thrushes, but probably also occurs in other species. The predawn peak in calling does not necessarily indicate that more birds are flying at that time. The peak may reflect an increased incidence of calling only, and not an actual increase in flight density. Our observations on a captive flock of six Swainson's Thrushes (*Hylocichla ustulata*), five Gray-cheeked Thrushes (*H. minima*), and one Veery (*H. fuscescens*) for a week in

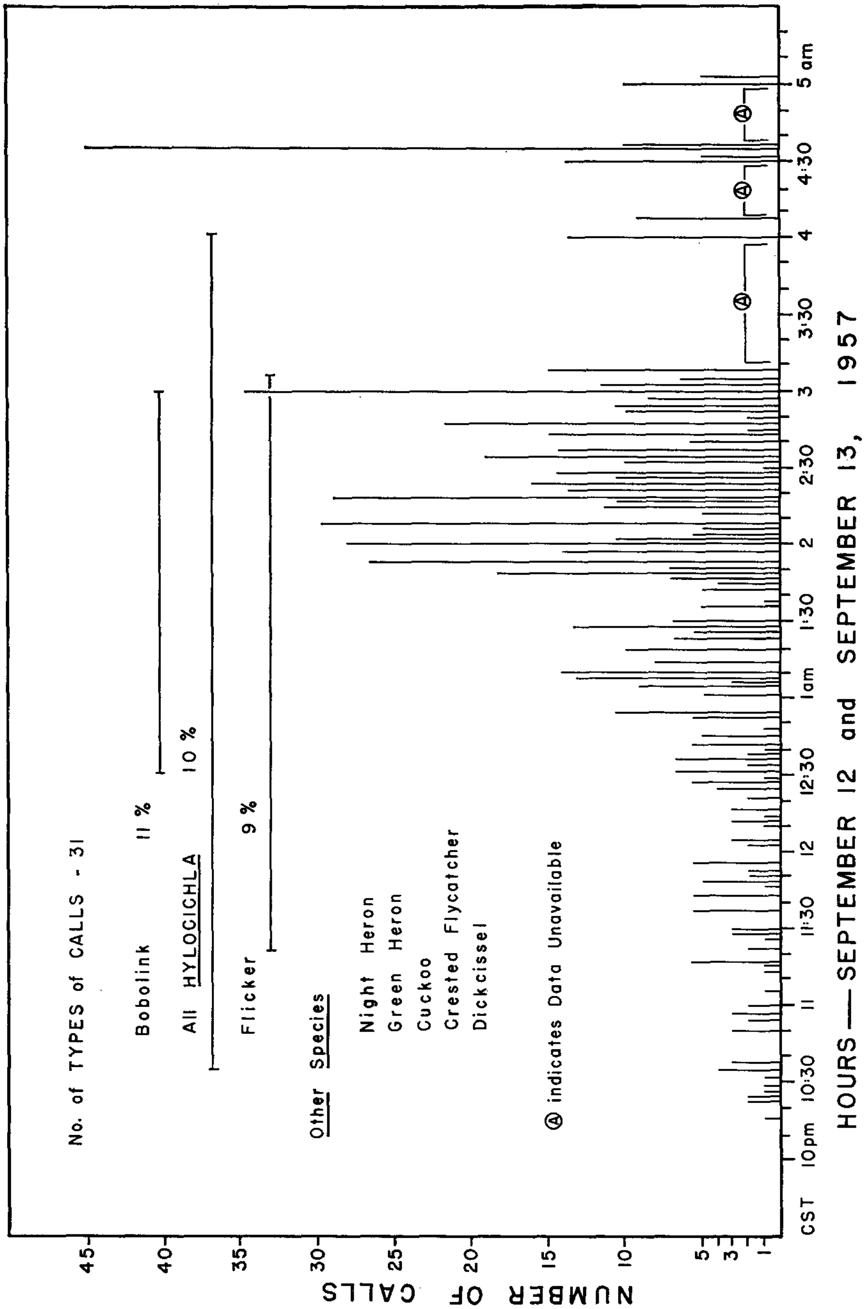
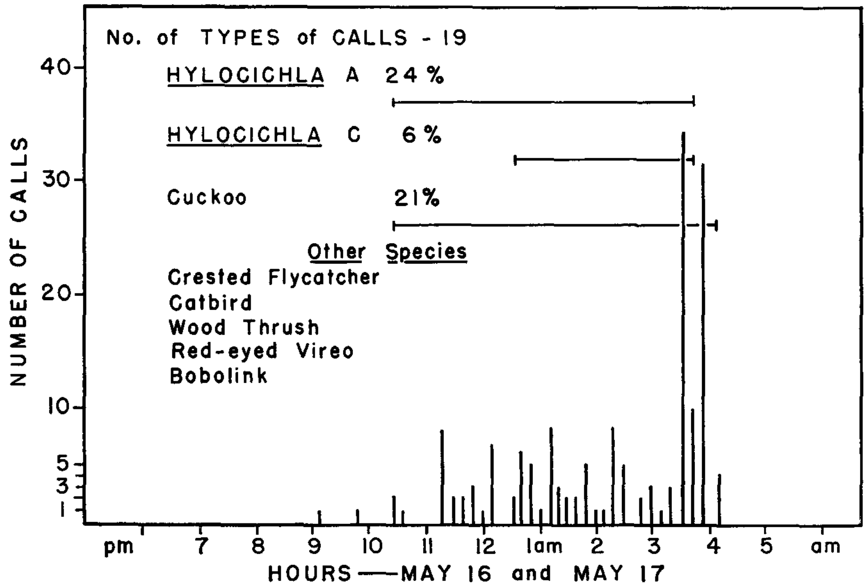
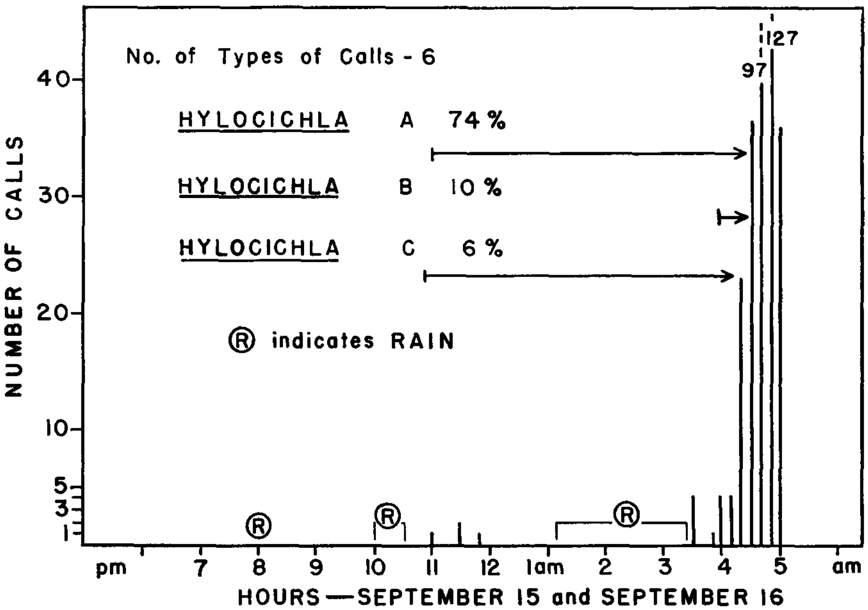
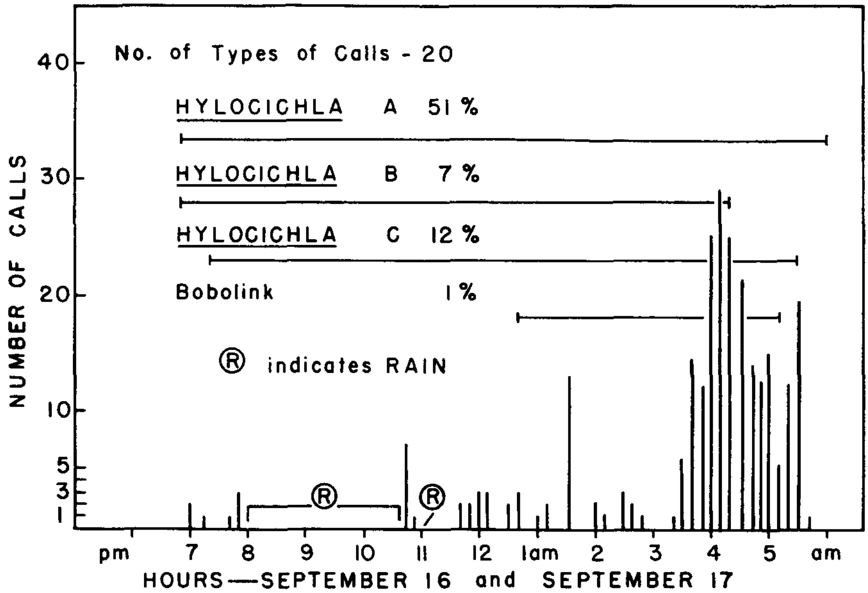


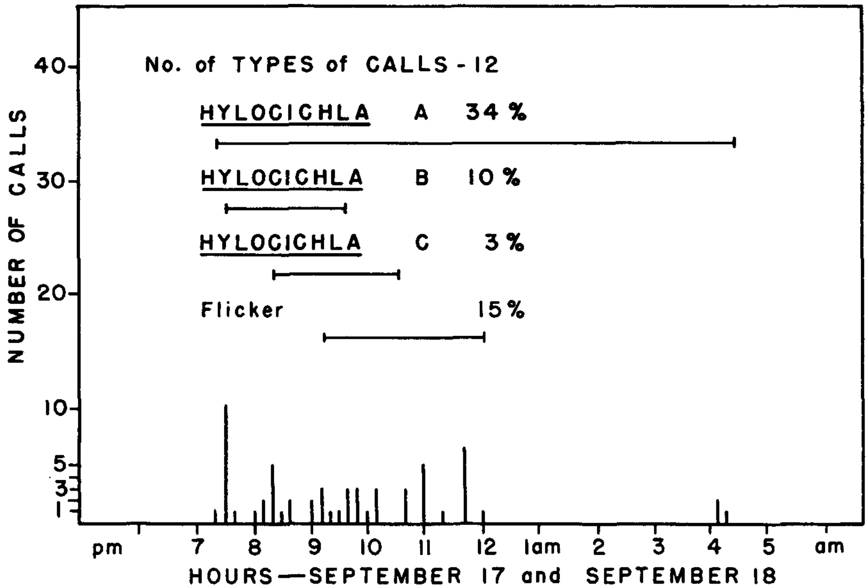
Fig. 4. Record of calls of nocturnal migrants transcribed from a continuous tape recording made on the night of September 12–13, 1957. Gaps marked "A" represent periods of power failure. Percentage figures represent per cent of total calls.





FIGS. 5 (above) and 6 (below). Records of calls of nocturnal migrants passing through a circular area with a maximum diameter of 912 feet on nights in 1958, near Champaign, Illinois. Histograms show number of calls recorded in 1½-minute periods every 10 minutes during the nights. Percentage figures represent per cent of total calls.





FIGS. 7 (above) and 8 (below). Records of calls of nocturnal migrants passing through a circular area with a maximum diameter of 912 feet on nights in 1958, near Champaign, Illinois. Histograms show number of calls recorded in 1½-minute periods every 10 minutes during the nights. Percentage figures represent per cent of total calls.

mid-September, 1958; and on two captive Gray-cheeks for three weeks in October corroborate the view that although these birds may call at almost any hour of the night, they actually call with greatest frequency in the predawn period.

It seems reasonable to assume that if some species, say Swainson's Thrush, is heard calling throughout the night the number flying may be just as great early in the night as late, but that a higher proportion of these thrushes call just before dawn than during the rest of the night.

Figs. 6–8, which show one complete migratory wave in the fall of 1958, help explain that any number of nightly patterns of migration may exist. Our recording station showed no evidence of nocturnal migration after 1 a.m. on September 15, but at 10:50 p.m. on September 15, the first loud calls (probably Gray-cheeked Thrushes) were recorded for a migration that was to continue throughout the night hours until the early morning of September 18 (Figs. 7 and 8). On the following night (September 19) there was little migration, and none of thrushes.

These records show that at least certain species of nocturnal migrants fly throughout the night as long as conditions prevail which favor migration.

Assuming a take-off time of 6:30 p.m. (September 15) and a flight speed of 35 mph, the first migrants of this wave probably started about 150 miles north of Champaign. If the front edge of this wave continued to move through the night hours as long as birds passed the Champaign station, the migration would have carried an individual bird about 900 miles by the morning of September 18, when the last birds passed Champaign.

The nightly migration patterns, then, at any given station depend upon the extent of the mass movement, the relative positions of the leading and trailing edges of the migrating mass of birds, and the geographic extent of the conditions which favor or retard migration.

Our data do not completely explain the discrepancy in nightly patterns of migration as determined by auditing with the unaided ear (Ball, 1952:55), and by lunar observations (Lowery, 1951:418). Both Lowery (1951:419) and Ball (1952:57) considered the possibility that migrants may fly higher (thus out of hearing) during the middle hours of the night than during the early and late hours of darkness. Both authors dismissed the possibility as improbable, but our data suggest that such an arc flight may be a reasonable explanation.

Flight Call Density

Fig. 4 shows the distribution and number of calls of nocturnal migrants during a heavy migration on the night of September 12–13, 1957. This record, in contrast to those shown in Figs. 5–8, is based on a continuous 7-hour tape recording, and the distribution of calls suggests that migrants were flocked, not evenly distributed in the sky. Ball's (1952:57) data also suggest an uneven (flocked) distribution of migrants. However, Lowery (1951:410) and Lowery and Newman (1955:246) present overwhelming evidence that nocturnal migrants are relatively evenly distributed in flight. It is entirely possible that it is only the calls, not the migrants, which have a "clumped" distribution. In fact, during the predawn peak in calling when the highest proportion of migrants are calling, the distribution of calls is not "clumped," but uniform and continuous.

In calculating flight-call density we have used the figures for the predawn peak as an index because they probably most nearly represent the true numbers of birds in flight.

Figs. 5 and 6 show peak numbers of calls per 1½ minutes for the heaviest migrations recorded in the spring (34) and fall (127) of 1958. These calls were emitted in an area with a maximum diameter of 912 feet. Lowery (1951: 434–436) gives spring flight-densities (number of birds crossing any part of a circle one mile in diameter per unit of time) for several localities. A maximum nightly density for Ottumwa, Iowa, in May was 54,600 birds. By comparison, the flight-call density for Champaign in spring (May 16–17) was 78,800 calls per 10 hours and in fall (September 15–16), 294,000 calls.

With regard to these calculations, the question arises as to whether an individual bird calls more than once as it flies through the area covered by the parabola. There is variation in frequency of calling between species and even by individual birds. Ball (1952:54) stated that a single Hermit Thrush (*Hylocichla guttata*) called at intervals of 12–13 seconds on a straight course, while in a curving flight down a hill slope it called at intervals of 6–9 seconds. Our observations in the vicinity of the Champaign audio station during many night and dawn periods of the past two years indicate that in the majority of cases each recorded call note represented a different bird. In straight flight at an average speed of 35 mph a given bird would be in range of the parabola for a maximum possible period of 18 seconds. Again our observations on captive thrushes are pertinent. In this flock, even in the predawn period, individual birds called only at intervals of several (2–45) minutes during nights in September and October.

Identification of Call Notes

The identification of species of birds from their nocturnal calls uttered in migration is a field of study in itself, and one which deserves more attention.

Some call notes may be learned through observations of migrants at dawn. Some birds may still be flying at this time, while others have alighted. An even better method is to listen to captive birds during periods when they exhibit *zugunruhe.*

We have been able to identify only a low percentage of the total number of calls on our tapes, and even so our identifications must be considered tentative. In Figs. 4–8 we have used letter designations for the thrushes rather than species names. "*Hylocichla* A" is probably Swainson's Thrush. The letter actually designates two types of calls which we have phoneticized as *whit* and *wheek.* We have heard Olive-backed Thrushes utter both these calls. "*Hylocichla* B" represents a call note which we phoneticized as *pee-oort,* while "C" represents the note *peer.* The latter two we have heard from Gray-cheeked Thrushes, but there is a possibility that the Veery may utter similar cries in migration.

Weather Conditions which Accompany Migration

Potentially, one of the most valuable types of data to be gained from audio studies is information on the conditions under which migration occurs.

For example, the mass migration of September 15–18, 1958 (Figs. 6–8), occurred largely with conditions of complete cloud cover and intermittent rains. At Champaign there was continuous 10/10 cloud cover from 7 a.m. September 15 until 7 p.m. September 17. At least part of this time the clouds were in three layers: 8/10 low stratus (top level at 1300–1500 feet), 3/10 strato-cumulo (base at 7000–8000 feet), and 10/10 probable ice clouds (base at 15,000–20,000 feet). Daily weather maps issued by the U. S. Department of Commerce for these dates show that the 10/10 overcast was extremely widespread, covering most of the states of Illinois, Wisconsin, Indiana, Iowa, and Missouri.

In the evening of September 16, birds began migrating at least by 6:35 p.m., not having seen direct sunlight all day at Champaign. Migration continued throughout the night with the possible exception of the periods of intermittent rain (see Fig. 4), at which times the audio technique was useless. It is possible that migrants actually flew through the rains because migrants were recorded immediately before and immediately after the precipitation. It is also possible that the birds were flying above the rain, but they had to be flying below the 15,000-foot ceiling or they would not have been detected by the audio equipment.

Under the conditions mentioned it does not seem likely that migrants were using celestial orientation as described by Sauer (1958:44).

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