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MONITORING GRASSLAND BIRDS IN NOCTURNAL MIGRATION

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Abstract. We censused vocalizations of night-migrating birds by making continual audio recordings of the night sky from a transect of seven recording stations across New York State in fall 1991–1993 and at one recording station in south Texas in spring 1995. Bird calls on these audio recordings were later detected by human listening and by automatic sound-detection software. Vocalizations of several migratory bird species that breed in North American grasslands were found on these recordings. We present basic evidence for the identification of nocturnal flight calls of migrant grassland birds east of the Rocky Mountains, and we introduce a method for quantifying nocturnal flight-calling that theoretically derives a minimum number of individuals passing over a recording station from analysis of calling data. Our recordings show that large numbers of certain grassland species can be detected by monitoring their nocturnal flight calls and that using a transect of recording stations can reveal migration corridors. Such information illustrates this monitoring technique's potential as an independent means of assessing population trends and migration pathways. Also evident is the potential for monitoring secretive species and species that nest in remote areas or regions difficult to census by other techniques. Information gained from monitoring nocturnal flight calls can be useful in determining locations for other avian monitoring operations, in making decisions regarding long-term habitat management, and in considering such questions as where to site communications towers and wind-turbine generator farms.

SUPERVISIÓN DE LAS AVES DE PASTIZAL EN MIGRACIÓN NOCTURNA

Sinopsis. Realizamos un censo de las vocalizaciones de aves que migran de noche haciendo grabaciones de audio continuas en el cielo nocturno desde un transecto de siete estaciones de grabación a lo largo del estado de Nueva York durante los otoños de 1991–1993 y en una estación de grabación en el sur de Texas en la primavera de 1995. Posteriormente, los reclamos de aves en estas grabaciones de audio fueron detectados a través de personas y a través de software de detección automática de sonidos. Se encontraron en estas grabaciones las vocalizaciones de varias especies de aves migratorias que se reproducen en pastizales norteamericanos. Ofrecemos pruebas fundamentales para la identificación de los reclamos nocturnos de vuelo de aves migratorias de pastizal del este de las Montañas Rocosas, y presentamos un método para la cuantificación de los reclamos nocturnos de vuelo en el que teóricamente se obtiene un número mínimo de individuos que están pasando encima de una estación de grabación a través de un análisis de los datos de reclamos. Nuestras grabaciones revelan que se pueden detectar grandes números de ciertas especies de pastizal controlando sus reclamos nocturnos de vuelo y que se pueden descubrir pasillos de migración utilizando un transecto de estaciones de grabación. Tal información ilustra el potencial de esta técnica de supervisión como una manera independiente de evaluar las tendencias poblacionales y los pasillos de migración. También es evidente el potencial para la supervisión de especies sigilosas y especies que anidan en áreas remotas o en regiones difíciles de empadronar con otras técnicas. La información recolectada por la supervisión de los reclamos nocturnos de vuelo puede ser útil para determinar lugares para otras actividades de supervisión de aves, para hacer decisiones con respecto al manejo a largo plazo de hábitat, y para considerar preguntas relacionadas con la ubicación de torres de comunicación y de haciendas con generadores de turbinas eólicas.

Key Words: grassland birds; migration; monitoring; nocturnal flight calls.

Many species of North American grassland birds migrate at night, and most of these species are known to vocalize while they fly (Appendix). Calling in night migration may help birds maintain in-flight associations (Hamilton 1962) and organize their spacing to minimize collisions (Graber 1968). Such calling can be monitored from ground-based audio recording stations (Graber and Cochran 1959). When species identities are known, analysis of audio data allows the number of calls for each species to be tallied and the passage of individual birds to be interpreted from sequences of successive calls.

In this paper we present information on nocturnal flight calls of North American grassland migrants and data from recent nocturnal flight-call monitoring studies. We discuss basic concepts behind this monitoring technique and its potential use for studying migration patterns and populations of many migratory grassland birds.

METHODS

We recorded nocturnal flight calls of migrating birds with two monitoring goals in mind: to determine which species migrate over a site and to evaluate each species' quantity of calling for comparison across time and place.

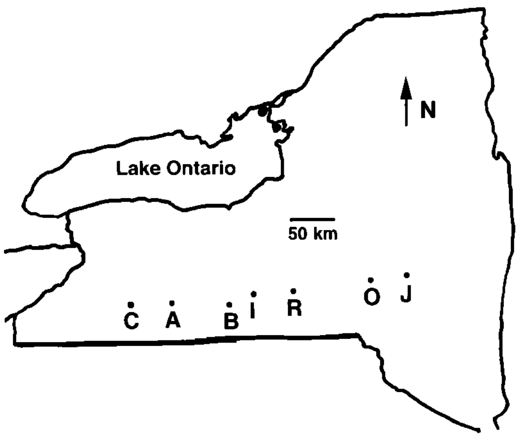

FIGURE 1. Approximate locations of nocturnal flight-call monitoring stations in New York State. Letter designations stand for the town nearest to the monitoring site (C = Cuba, A = Alfred, B = Beaver Dams, I = Ithaca, R = Richford, O = Oneonta, J = Jefferson).

Recording Stations

The technical goal of recording nocturnal flight calls is to receive sound from the airspace above a recording site while minimizing the reception of environmental ground noise. To achieve this goal, microphones must have directional sensitivity patterns and be aimed at the sky. Depending on their monitoring goals and the recording environment, researchers have used a variety of different microphone and recording-station designs (Graber and Cochran 1959, Dierschke 1989, Evans 1994). In this study we used various pressure-zone microphone designs. In Texas, for example, we surface mounted a Knowles EK3024 hearing-aid microphone element to the center of a 25-cm-diam plastic dinner plate. The simple electronic circuit that powered the microphone element was attached to the bottom of the plate, and clear plastic wrap was stretched and sealed across the upturned edges of the plate as a sound-permeable waterproof membrane. This microphone mount theoretically doubled the sound pressure (for sound frequencies > 1,500 kilohertz [kHz]) in the direction that the face of the plate was pointed. The plate was mounted 23 cm deep inside a 42-cm-deep plastic flowerpot that had a 48-cm-diam top aperture. The inside walls of the flowerpot were lined with acoustic foam to absorb sound reflections, and cheesecloth was fastened over the top to keep out debris. The flowerpot structure helped block out ground-born environmental noise. The overall microphone system provided an inexpensive, highly directional microphone that was very sensitive in the 2–9 kHz band, which is the frequency range of most avian nocturnal flight calls east of the Rocky Mountains.

In fall 1991–1993, from late July through October, we operated an east-west transect of up to seven recording stations spanning approximately 300 km across central New York State (Fig. 1). In spring 1995, from mid-March through late May, we operated a recording station at Laguna Atascosa National Wildlife Refuge (NWR), about 30 km north of Brownsville, Texas. All of these recording stations consisted of pairs of pressure-zone microphones mounted on the roofs of buildings. The audio signals were recorded on soundtracks of high-fidelity video-cassette recorders. Video tapes recorded 8–9 hr of sound per evening. The equipment was operated by refuge staff in Texas and by volunteers in New York.

Nocturnal Flight-call Analysis

Nocturnal flight calls were detected on the recordings by listening with headphones and by automatic extraction with signal-analysis software written in the Bioacoustics Research Program at the Cornell Laboratory of Ornithology. This software is designed to detect short, high-pitched sounds in the 5–10 kHz frequency range. Stereo recordings were analyzed from New York. Single-channel and stereo recordings were analyzed from Texas.

Identification of the extracted nocturnal flight calls was performed by aural comparison or by visual comparison of spectrograms to calls of verified identity for each species. Recordings of the known calls had been made in daytime while the species was visually identified. All spectrographic analysis was carried out using the software program Canary (Charif et al. 1995). Spectrograms of calls presented in this paper were made from calls digitized with a 22,254-hertz (Hz) sampling rate and were processed using a 256-point fast Fourier transform (FFT), 128-point frame size, 87.5% overlap, and Hanning window (frequency resolution 86 Hz, time resolution 0.72 ms, analysis bandwidth 700 Hz).

After a night's calls were detected and identified to species, the calling data were analyzed by interpreting call sequences to derive a minimum number of individuals passing (MIP). This interpretive technique considers information such as time delays in calling, amplitude differences between closely occurring calls, stereo spatial separation, the species of the caller, expected flight speeds, and the pickup pattern of the microphone(s). The MIP technique is a conservative estimate that is likely to be more accurate for quantitative population studies than counting the total number of calls because it compensates for the variable calling rates of individual birds.

An example of how we used the MIP technique in this study is illustrated with Grasshopper Sparrow (*Ammodramus savannarum*) and Savannah Sparrow (*Passerculus sandwichensis*) data from a single audio channel recorded at Laguna Atascosa NWR. The formula used to calculate MIP counts for these two species was based on the assumption that migrating individuals were moving toward some distant location on a horizontal plane so that nearly all individuals were passing on a relatively straight-line course through the zone of microphone sensitivity. In addition, we applied previously determined information on the pickup pattern of the microphone and a conservative estimate of the birds' flight speed on the evening of 5–6 April 1995.

The pickup pattern of a microphone design was determined using a ground-based eight-channel microphone array. Eight microphones were laid out in a 75-

× 75-m area—four at the corners of the area and four at the corners of a 30- × 30-m square centered inside the large square. This layout enabled calls from birds flying in the vicinity of the array to be picked up by all eight microphones. It also enabled the approximate point of origin of a nocturnal flight call to be determined by analyzing its varying arrival times at the different microphones. By plotting such locations for hundreds of nocturnal flight calls, the shape of a microphone's detection pattern and its range of detection for different species became evident. The detection range is defined here as the distance in which a call could be picked up by the microphone and still be identified to species by spectrographic analysis. This range varied because of differing call loudness among species, the distinctiveness of the species' acoustic signatures, and variables in a recording site's environmental noise. The eight-channel study revealed that the microphone design used in Texas had a maximum detection range above ground of less than 300 m for a wide range of different warblers and sparrows, including Savannah Sparrow. Furthermore, the maximum horizontal cross-section of sky a single microphone had for detecting such calls was less than 250 m.

In calculating MIP counts through the region of sensitivity from a single microphone, the detection range determined by the eight-channel study was modified to make the estimate a conservative one. The minimum ground speed of passing migrants was assumed to be 20 km/hr, a likely underestimate for average small-passerine ground speed when these birds have a following wind. We also assumed that the longest horizontal cross-section of the microphone sensitivity region was 300 m, a conservative revision of the eight-channel measurement. A Grasshopper or Savannah sparrow flying at 20 km/hr travels about 330 m/min and would typically pass through the region of microphone sensitivity in less than 1 min. Therefore, the first factor used in calculating the MIP for Grasshopper or Savannah sparrows was that calls from one of these species occurring more than 1 min apart were considered to be different individuals of that species.

The second factor used to calculate MIPs was based on 80 hr of listening to stereo recordings containing hundreds of sparrow calls. These data showed that Savannah and Grasshopper sparrow calls occurring within 3 sec of one another in a single microphone recording were almost certainly from two different individuals and not the same individual calling twice. We determined this because the stereo resolution of the microphones allowed a rough spatial assessment of call location (i.e., off to the right or off to the left). If the same bird called twice within 3 sec, these calls would sound as if they came from roughly the same stereo-resolved position and were of similar amplitude. This type of occurrence was quite rare. Such adjacent temporal calls almost always sounded as if they were from birds widely separated in space and often were of different amplitude. The second MIP criterion, therefore, was that calls from the same species occurring within 3 sec of one another were tallied as separate individuals.

A separate statistical analysis used correlations to examine the relationship between the observed hourly detections of Bobolinks (*Dolichonyx oryzivorous*) at all New York recording stations. Differences were considered significant at $P = 0.05$. The Bonferroni correction for multiple inference was used to correct for multiple tests to ensure an experiment-wide significance level of 0.05.

RESULTS

IDENTIFICATION OF NOCTURNAL FLIGHT CALLS

Confirming the identity of nocturnal flight calls for certain species of grassland birds (e.g., Upland Sandpiper [*Bartramia longicauda*], Long-billed Curlew [*Numenius americanus*], Dickcissel [*Spiza americana*], Bobolink) is simple because they give the same distinctive calls at night that they give during the day. In many species of grassland sparrows, however, the short, high-pitched nocturnal flight calls are not commonly given during the day, making verification difficult. Many of these sparrows' calls also sound similar to one another and can be hard to discriminate by ear. The diurnal counterpart of a sparrow's nocturnal flight call is termed a "flight note" for some species because it is often heard while the bird is flying. For other species, this diurnal counterpart is often called a "location call," as it may not be given in flight as much as while the bird is on the ground in dense grasses. These short notes are often called "tseep notes," a phoneticization of the way many sparrow calls sound. In all cases, whether given at night or during the day, these calls apparently serve to make or maintain contact with other birds.

A primary step in establishing the identity of an unidentified sparrow nocturnal flight call is to obtain recordings of diurnal tseep notes for spectrographic comparison. Figs. 2 and 3 compare nocturnal flight calls from the evening of 5–6 April 1995 with diurnal recordings of verified identity. We classified these nocturnal flight calls as Grasshopper and Savannah sparrow calls based on the similarity of their time-frequency contour with that of the diurnal tseep notes given by these two species, and also because no other species migrating in the Laguna Atascosa NWR region are known to give such call types. Fig. 4 illustrates diurnal tseep notes for five other grassland sparrows and diurnal flight calls of verified identity for four other grassland species. Such call types have been recorded at night in this study or in studies not discussed here. The appendix provides further information on what is known about the nocturnal flight calls of grassland birds east of the Rocky Mountains.

TEXAS

During 5–15 April 1995, four species of North American grassland migrants were acoustically detected by the recording station at La-

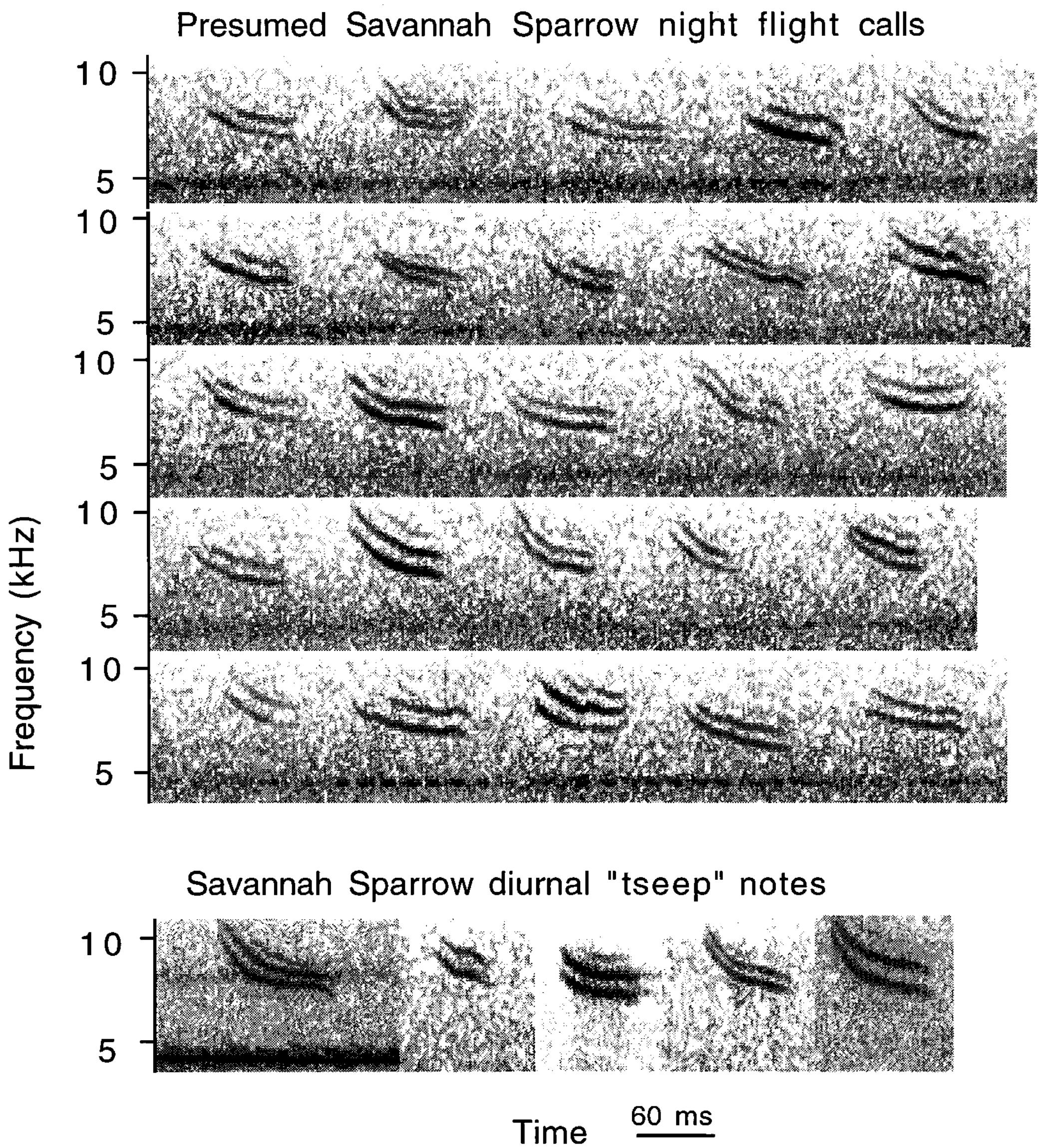

FIGURE 2. Comparison of Savannah Sparrow diurnal and presumed nocturnal flight-call spectrograms. Diurnal flight notes were recorded in south Texas (first two), west Texas (third), Oklahoma (fourth), and North Dakota (fifth). Presumed Savannah Sparrow nocturnal flight calls were recorded on the night of 5–6 April 1995 at Laguna Atascosa NWR, Texas.

guna Atascosa NWR. Most of the identifiable calls were spectrographically classified as Grasshopper or Savannah sparrow calls. For example, of the 385 calls automatically detected on one audio channel during 8 hr of monitoring on the evening of 5–6 April, 78 (22%) were classified as Grasshopper Sparrow and 89 (25%) as Savannah Sparrow (Fig. 5). The MIP technique estimated that at least 54 Grasshopper Sparrows and 57 Savannah Sparrows flew over the recording station during this night's monitoring period.

On most nights in the study period, only small numbers of sparrow calls were recorded (< 50 calls in 8 hr). These low-calling nights corresponded with evenings of east to southeast winds over this part of Texas. Wind data from Brownsville, Texas, indicated that the large sparrow-calling event on the night of 5–6 April occurred when there was a shift from calm con-

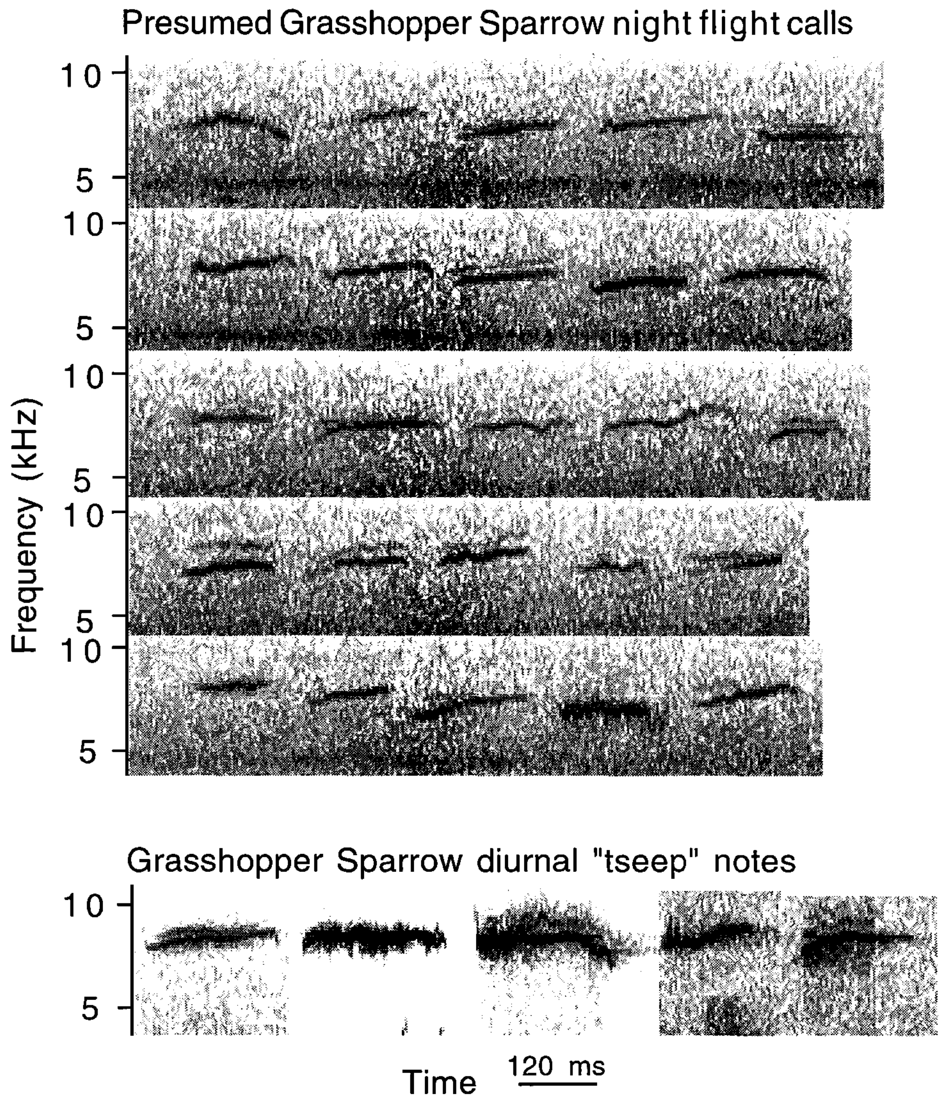

FIGURE 3. Comparison of Grasshopper Sparrow diurnal and presumed nocturnal flight-call spectrograms. Diurnal flight notes were recorded in Florida (first two), Texas (third and fourth), and Alabama (fifth). Presumed Grasshopper Sparrow nocturnal flight calls were recorded on the night of 5–6 April 1995 at Laguna Atascosa NWR, Texas. Note that the time scale is more condensed than in Fig. 2.

ditions to a steady wind out of the southwest during the evening (Fig. 6).

Listening to recordings and using the MIP technique to analyze data also revealed that at least 26 Upland Sandpipers and 28 Long-billed Curlews passed over the recording station during 5–15 April 1995. Later in April and in early May 1995, thousands of Dickcissel calls and five incidences of Black Rail (*Laterallus jamaicensis*) nocturnal flight calls were recorded. The MIP method has not yet been applied to the Dickcissel calling data.

NEW YORK

The transect of New York recording stations revealed calls from Upland Sandpipers, Bobolinks, and several grassland sparrows. Upland Sandpiper counts were detected in larger numbers toward the west end of the monitoring array than the east end, with an average of 13.3 and 12.0 per year detected over 3 yr at the western stations A and B, respectively. In the same period, the eastern station O averaged only 4.0 Upland Sandpiper calls per season (Table 1). In contrast to Upland Sandpipers, Bobolinks passed

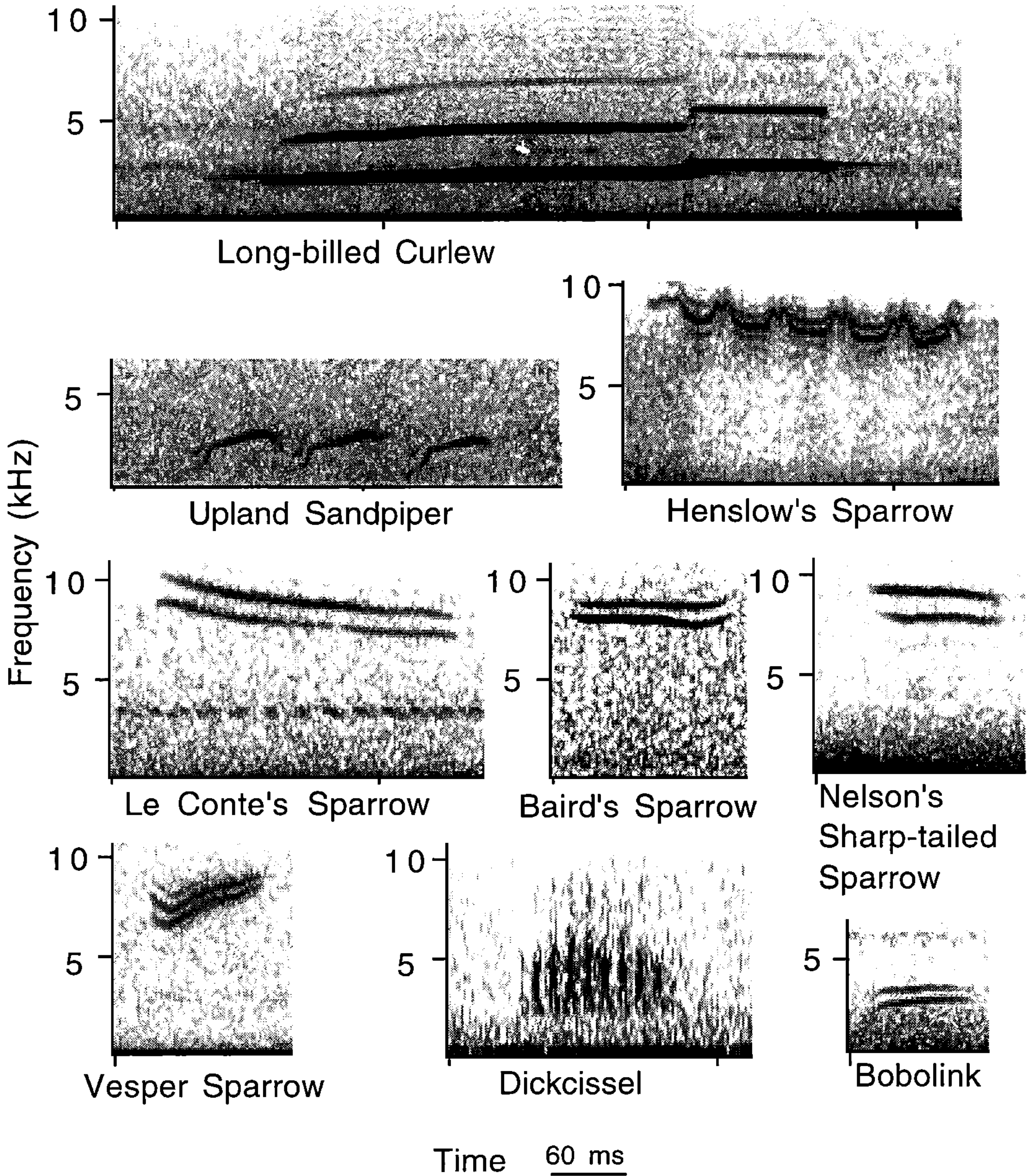

FIGURE 4. Diurnal calls from a variety of grassland breeders in eastern North America. All recordings were made during the day when the species' identities were observed. Calls similar to these have often been recorded at night during migration.

over the east end of the array in larger numbers than they did over the west end (Table 1). Station O recorded the four largest nights of Bobolink passage during 3 yr of monitoring and consistently had the highest season total. From 1991 to 1993, data from stations in the New York transect indicated the period of fall Bobolink migration, with a peak from the last week in August through the first week of September (Fig. 7). Nights with southerly winds were not monitored, as previous experience had shown that very few calls are detected on such nights in this region.

Because of differences in coverage between stations and seasons, statistical comparison of the Upland Sandpiper and Bobolink season total

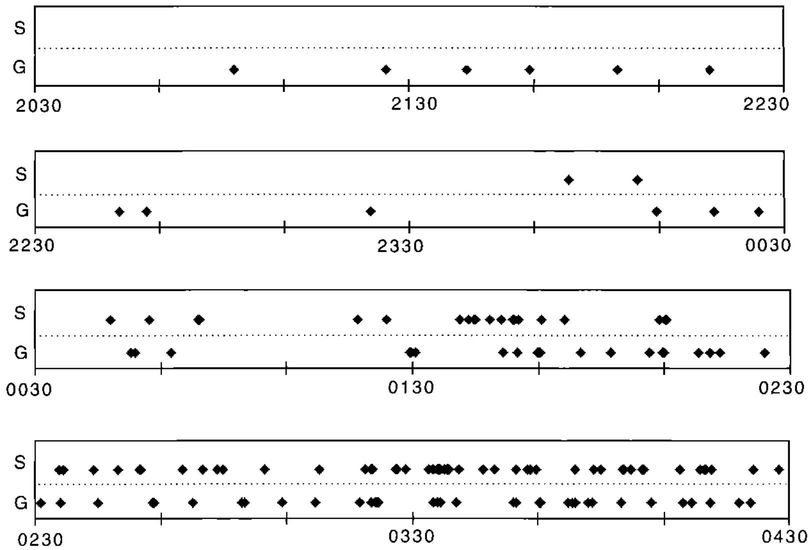

FIGURE 5. Temporal occurrence of Grasshopper and Savannah sparrow calls detected from one audio channel at Laguna Atascosa NWR, Texas, on the night of 5–6 April 1995 (1930–0330 central standard time). S = Savannah Sparrow calls, G = Grasshopper Sparrow calls.

data is not possible. The number of nights recorded at each location per season varied depending on weather and occasional equipment failure. The data are presented to give a rough count of the minimum number of these species that may be detected from recording stations in this region.

Bobolink data from the recording stations across New York revealed correlations in the hourly density patterns between stations (Table 2). Five of the seven stations had their highest correlation with a neighboring station. Patterns of hourly counts at the two eastern stations, O and J, were correlated ($r = 0.87$, significant at $P < 0.05$) and appeared to have relatively large, similar counts, with a peak in the fifth hour. Stations in the middle of the array (B, I, and R) had a highly correlated but uniformly smaller passage, with a density peak in the fourth hour (I-B: $r = 0.99$; I-R: $r = 0.89$; R-B: $r = 0.93$; all significant at $P < 0.05$). Stations A and C, at the west end of the array, had a less correlated temporal pattern ($r = 0.57$, not significant at $P < 0.05$) but also showed the density peak in the fourth hour.

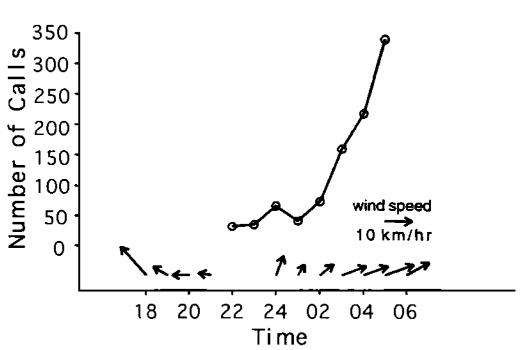

FIGURE 6. Hourly wind direction and speed at Brownsville, Texas, indicated by the direction and length of arrows (lower) compared with the rate of nocturnal flight calls detected per hour by ear (upper) from a stereo recording at Laguna Atascosa NWR, Texas. Data are from the night of 5–6 April 1995 between 2100 and 0500 central standard time.

DISCUSSION

An important facet of nocturnal flight-call identification is that certainty in call identification is based partly on the process of elimina-

TABLE 1. NUMBER OF UPLAND SANDPIPERS AND BOBOLINKS DETECTED DURING FALL MIGRATION AT RECORDING STATIONS IN NEW YORK STATE, 1991–1993

		Year			
Species	Station	1991	1992	1993	Mean
Upland Sandpiper	A	12	15	13	13.3
	B	6	19	11	12.0
	O	2	2	8	4.0
Bobolink	A	ND[a]	126	140	130
	B	ND	75	85	80
	O	162	140	418	240

[a] ND = no data.

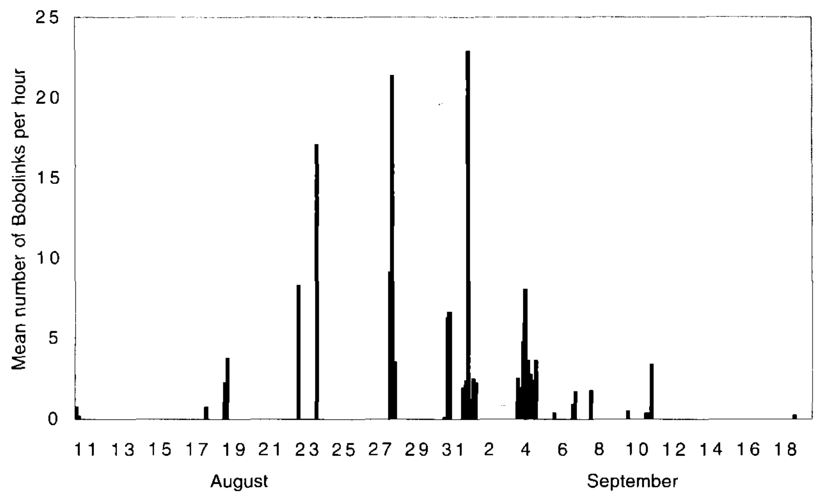

FIGURE 7. Mean number of Bobolinks per hour detected by the MIP technique at stations A, B, and O in New York State during fall migration 1991–1993. Each migration night was monitored for 8 hr. Nights with southerly winds were not monitored. The three highest hourly rates were documented from station O. Because all years and station data are plotted together, the plot illustrates variability on a particular recording date. Since major migration happened to occur on the same nights in several seasons, data have a clumped appearance.

tion. One cannot know that a certain nocturnal flight call is given by a particular species until one knows that other species do not give a similar call. An archive of diurnal tseep notes and flight calls is nearly complete for passerines that migrate east of the Rocky Mountains (W. R. Evans and M. O'Brien, unpubl. data). This body of evidence, some of which is illustrated in Figs. 2–4, is a primary tool that we used to support the nocturnal flight-call species identifications in this paper. Such call types are believed to be the same ones given in night migration by these species.

Our five diurnal-call examples of Grasshopper and Savannah sparrows (Figs. 2 and 3) are not a sufficiently large dataset to define the range of variation of these species' tseep calls. They do, however, give an idea of the basic time-frequency contour of these calls, and it appears unlikely that these two species could be confused because their call types are so distinct from one another. The calls of the other migratory species common in the Laguna Atascosa NWR region of Texas are known and are distinct from the basic time-frequency contours of Savannah and Grasshopper sparrow calls.

TABLE 2. HOURLY TOTALS OF BOBOLINKS DETECTED AT RECORDING STATIONS ACROSS NEW YORK STATE ON THE NIGHT OF 28–29 AUGUST 1993

	Recording station						
Hour	C	A	B	I	R	O	J
1930–2030	3	14	0	0	2	12	0
2031–2130	5	23	0	0	0	4	0
2131–2230	19	7	4	7	2	37	6
2231–2330	33	25	14	18	17	32	27
2331–0030	10	2	3	4	9	63	38
0031–0130	3	1	0	2	0	21	8
0131–0230	1	1	0	0	0	1	0
0231–0330	0	0	0	0	0	1	0

Identification of other species of grassland sparrows is not as clear. For example, spectrographic analysis of diurnal tseep calls of Baird's Sparrow (*Ammodramus bairdii*), Le Conte's Sparrow (*A. leconteii*), and Nelson's Sharp-tailed Sparrow (*A. nelsoni*) show that although the calls appear to have distinctive characteristics, they are similar enough that variations of their nocturnal flight calls could overlap (Fig. 4). Larger diurnal datasets and study of nocturnal datasets from different geographic regions are necessary to define variations in these species' calls before they can be distinguished at night in regions where the species migrate together. Calls illustrated in this paper are not meant to definitively identify nocturnal flight calls but to provide preliminary identification characteristics and to illustrate the concept of nocturnal flight-call identification.

Our Texas data illustrate the type of information that can be gathered from a single monitoring station operated through a migration season. A calling record can be obtained that yields a minimum number of individuals passing over the recording site through time. The Texas data produced evidence that at least six species of North American grassland breeders migrated over Laguna Atascosa NWR. Baseline information was gathered on the volume of calling from Black Rail, Upland Sandpiper, Long-billed Curlew, Savannah and Grasshopper sparrows, and Dickcissel. The Black Rail detections were significant because the species was not known to currently winter or migrate through southernmost Texas. The significance of the acoustic data for the other species will not be revealed until future use of the acoustic-monitoring technique produces comparative data from other regions or seasons. For example, there may be no other region of North America where dozens of Long-billed Curlews can be detected in nocturnal migration.

The timing of calls within evenings also revealed interesting patterns. On 5–6 April 1995 at Laguna Atascosa NWR, the rate of calling of Grasshopper and Savannah sparrows increased greatly after 0130 central standard time (Fig. 5). This increase is thought to be due to a change from calm conditions to a steady wind from the southwest (Fig. 6). Such a change would tend to wind-drift migrating passerines toward the Gulf Coast. As birds reached the coast, many probably adjusted their northerly heading to avoid getting carried out over the water, resulting in an increased number of birds migrating in the coastal region.

The formula used to tabulate the MIP for Grasshopper and Savannah sparrows gives a conservative estimate and is meant to illustrate a basic example of this new method for interpreting nocturnal flight-calling data. In cases where three or more calling birds pass over a single microphone at about the same time, the MIP technique counts at least one individual passing but may not be able to distinguish two or more. Such distinctions depend on the number and sequence of calls by each individual and the birds' positions in space. Use of radar to characterize small-passerine flight speeds in relation to varying weather conditions could improve the accuracy of the ground-speed component in the MIP formula. Further research on MIP methods could reveal distinctive calling patterns characteristic of three or more birds passing in 1 min. In addition, analysis of factors such as varying call amplitude could be incorporated. Such advancements could be reapplied to the data presented here to produce a more accurate MIP count.

Our Texas data illustrate the limitations of operating a single monitoring station. The recording station at Laguna Atascosa NWR was within 8 km of the southeast coast of Texas. Data from the station showed a low number of passerine calls detected on nights when winds were from the southeast—the region's most common spring wind direction. More calls were detected on nights of relatively rare southwesterly winds. This coastal recording location, where the density of migrating passerines appears to be dependent on wind direction, therefore may not be a reliable location for quantitative studies of migrant passerines aimed at population monitoring. One way to compensate for the effects of wind and geographic location on the consistency of nocturnal flight-call monitoring would be to set up a line of inland recording stations, as we did in southern New York.

The New York transect revealed many interesting results. Interpretations of these data, however, raise further questions. For example, the cause of the fall Bobolink density pattern (Table 1) across the New York transect is unknown. One possibility is that the pattern reflects breeding distributions to the north. Another is that the pattern is caused by birds flying around Lake Ontario. The hourly density pattern on the night of 28–29 August 1993 suggests passage around Lake Ontario because of the larger density at the east and west ends of the transect compared with smaller passages across the middle stations (Table 2). The uniform density increase across the transect during the fourth hour indicates that a wave of Bobolinks may have crossed Lake Ontario. Night migrants typically take off 0.5–1 hr after sunset (Hebrard 1971; Richardson 1972; W. R. Evans, unpubl. data), which was at approximately 1840 eastern standard time. Ground speed in small passerines is variable, but with following winds, speeds of 40–80 km/hr have been measured (Cochran et al. 1967, Cochran 1987, Berthold 1993). The northern shoreline of Lake Ontario is roughly 240 km north of the recording transect, so migrants would cross the transect 3–6 hr after takeoff, or at approximately 2210–0110. The observed peak hour was in fact 2230–2330, within the expected arrival period.

Regarding the broad-front correlation in Bobolink detections on 28–29 August 1993, weather factors were probably not involved because clear skies and light northerly winds prevailed across the region. The parallel, east-west geographic position of Lake Ontario in relation to the recording transect may have aided this correlation. The relatively similar hourly counts between neighboring stations suggest a broad-front character to Bobolink migration in this region. Because stations are 51 km apart on average, the acoustically detected Bobolink flight on 28–29 August 1993 tended to cross the transect in broad, related density fronts at least 50 km wide. This phenomenon raises the possibility that for certain species, if a monitoring transect is positioned appropriately, the flight density between stations may be interpolated and an estimate of the minimum number of birds crossing a transect may be calculated. Local topography, which may affect migration patterns, would need to be considered in this interpolation. Such potential greatly increases the population-estimation power of this monitoring method. Detecting a greater fraction of individuals in a given area theoretically makes a monitoring operation's estimates more sensitive to population change through time.

The Bobolink and Upland Sandpiper data from New York illustrate a basic idea of nocturnal flight-call monitoring: by recording calling through a migration season for several years, baseline data are established on the number of acoustic detections expected in a region. Even with only three seasons of monitoring, certain acoustically determined density patterns appear to be indicated across central New York. Continued monitoring may reveal population trends.

An ideal monitoring operation for grassland birds might consist of several east-west lines of recording stations stacked north-south, perhaps 50–100 km apart. Research on the appropriate interstation distance in such transects is still needed. Our results suggest that an interstation distance of 50 km may be suitable for broad-front detection of some species; however, this distance may vary in different geographic regions. A multi-tiered network would allow broad waves of migrants to be tracked as they move north or south, providing a means for acoustic monitoring to validate its results. Waves of birds crossing one line of stations could be resampled crossing second and third lines.

One of the impediments to such monitoring is the large quantity of acoustic data to be analyzed. Developing signal-processing software to facilitate data analysis is a key step in handling this volume of data. Automatic call-detection technology has already greatly assisted data analysis. Research on automatic-processing technology is in progress (e.g., Mellinger and Clark 1993, Fristrup and Watkins 1994) and holds great promise for the nocturnal flight-call monitoring technique.

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APPENDIX. MIGRANT GRASSLAND BIRDS EAST OF THE ROCKY MOUNTAINS, WITH AN INDICATION OF WHETHER THEY ARE KNOWN TO CALL IN NIGHT MIGRATION AND A DESCRIPTION OF THEIR FLIGHT CALL

Species	Nocturnal flight-call information
Yellow Rail *Coturnicops noveboracensis*	No. A night migrant based on tower-kill data (e.g., Baumgartner 1961), but no nocturnal flight call is known.
Black Rail *Laterallus jamaicensis*	Yes. *Kee kee kerr* or *kee kerr.* Similar to distinctive diurnal calls.
Upland Sandpiper *Bartramia longicauda*	Yes. A strident chatter series similar to alarm chatter given on breeding ground (Fig. 4). May also migrate diurnally.
Long-billed Curlew *Numenius americanus*	Yes. *Ker-lee* series or variations. Similar to diurnal calls (Fig. 4). May also migrate diurnally.
Horned Lark *Eremophila alpestris*	Yes. Distinctive diurnal flight note has occasionally been detected at night. Thought to be primarily a diurnal migrant.
Sprague's Pipit *Anthus spragueii*	No. Distinctive *squeet* diurnal flight note has not been detected at night. May be primarily a diurnal migrant.
Sedge Wren *Cistothorus platensis*	No. A night migrant based on tower-kill data (e.g., Graber 1968), but no nocturnal flight call is known.
Dickcissel *Spiza americana*	Yes. A low *bzrrt* note. Similar to diurnal flight call (Fig. 4). Also migrates diurnally.
Cassin's Sparrow *Aimophila cassinii*	No. Diurnal location call is not known. No nocturnal flight call is known.
Vesper Sparrow *Pooecetes gramineus*	Yes. A high, thin *tseep.* Similar to diurnal flight note or location call (Fig. 4).
Lark Sparrow *Chondestes grammacus*	Yes. A dry *tsip.* Similar to diurnal flight note.
Lark Bunting *Calamospiza melanocorys*	No. Distinctive *tew* flight note has not been recorded in night migration. May be a diurnal migrant. Some tower-kill data (e.g., Avery et al. 1978) suggest night migration.
Savannah Sparrow *Passerculus sandwichensis*	Yes. A high *tsew.* Similar to diurnal flight note or location call (Fig. 2).
Grasshopper Sparrow *Ammodramus savannarum*	Yes. A high *tsee.* Similar to diurnal location call (Fig. 3).
Baird's Sparrow *A. bairdii*	No. Believed to give a high *tsee* note based on diurnal recordings by M. T. Green (Fig. 4). Call is similar to that of certain other sparrows and has not yet been distinguished at night.
Henslow's Sparrow *A. henslowii*	Yes. A high descending *tzeee.* Similar to diurnal location call (Fig. 4).
Le Conte's Sparrow *A. leconteii*	Yes. A high descending *tseew.* Similar to diurnal location call (Fig. 4).
Nelson's Sharp-tailed Sparrow *A. nelsoni*	Yes. A high sibilant *tsew* or *tsee.* Similar to diurnal location call (Fig. 4).
Eastern Meadowlark *Sturnella magna*	No. Diurnal flight note (*klee*) has not been detected in night migration. May be primarily a diurnal migrant.
Western Meadowlark *S. neglecta*	No. Diurnal flight note (*klee*) has not been detected in night migration. May be primarily a diurnal migrant.
Lapland Longspur *Calcarius lapponicus*	Yes. A *tew* note similar to calls occasionally heard during the day amidst more common rattle calls. Night migration may be initiated by snowstorms (S. Seltman, pers. comm.). Other longspur species may exhibit similar behavior, though they are thought to be primarily diurnal migrants.