Autumn Migration and Weather in Eastern Canada: A Radar Study

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So vast is the literature reporting field studies of migration that one might suspect that the topic is exhausted. Indeed, there are those who believe that in the future significant progress will be made only by laboratory studies. These impressions are false. We know little about migration in most specific areas or about interspecific differences in behavior. Field observations are useful even to the experimentalist since they suggest questions that may be answered experimentally. While lab studies are of great value to those working on orientation or migratory responses to weather, experience has shown that the results of this work need to be checked against the behavior of free-flying birds. For example, while planetarium experiments suggest that nocturnal migrants do not orient when they cannot see the stars (Sauer, 1957; Emlen, 1967), radar studies show that birds are often well-oriented when flying under opaque overcast (Drury and Nisbet, 1964; Bellrose, 1967). Thus field studies of migration are still needed.

For the past several years I have been using radars to study the patterns, timing and orientation of migration in southeastern Canada. In an earlier issue of this journal I summarized the spring data (Richardson, 1971). The present report is a parallel summary of some of the autumn results.

METHODS AND DATA OBTAINED

The techniques used were identical to those employed in spring, and the reader is referred to the spring report for additional details. However many more autumn than spring data have been collected.

(i) Nearly continuous time-lapse films of the displays of the following four surveillance radars in Nova Scotia and New Brunswick were made: Barrington, N.S. (1 2/3 autumn migration seasons), Halifax, N.S. (2 1/3 seasons), Sydney, N.S. (1½ seasons), and St Margarets, N.B. (1½ seasons). Figure 3 shows the locations of these sites. Since the periods of filming at Barrington and Halifax did not overlap. I collected autumn data from central or western Nova Scotia on a total of about 275 different days in four different years.[1] The direction and speed distributions of the migrants plus the amount of migration[2] were evaluated several times each day and night from these films.

(ii). I used height finding radars to measure the heights of autumn migrants near Barrington (observations several times a day for 9 weeks), St Margarets (6 weeks) and Sydney (1 week).

(iii). The directions of migrants near various radars in Quebec and the Maritimes (Fig. 3-10) were determined each day and night between October 10 and 30, 1970 from PPI displays showing digitized radar data. Richardson (1971 and in press) describes the technique and its limitations.

HOUR-TO-HOUR DENSITY CHANGES

As is the case elsewhere in North America (Drury and Keith, 1962; Richardson, 1970) the average density of migration at night was much greater than that by day. When the weather was favorable large numbers of passerines took off one half to three quarters of an hour after sunset. After midnight the density decreased gradually. Around sunrise the remaining passerine echoes were usually replaced by strong echoes from flocks of diurnal migrants. Diurnal migration often continued all day. Deviations from this typical pattern usually occurred when the weather conditions were changing.

When the weather was favorable the density often began to increase an hour or two before sunset. These late-afternoon departures consisted of shorebirds and perhaps waterfowl. They continued to fly after dark and were joined by the passerines about one half hour after sunset

DIRECTIONS OF MIGRATION

SW migration — The predominant directions of autumn migration in the Maritimes, both by day and by night, were SSW-WSW. This is approximately parallel to the NE-SW aligned

1. Medium-powered AASR-1 (22.5 cm) and ASR-5 (10.7 cm) Air Traffic Control radars were used at Halifax (Richardson, in press). St Margarets has a high-powered L-band radar similar to those used by Drury and Nisbet (1964) and Richardson and Gunn (1971). Barrington and Sydney have very high-powered S-band radars. The Halifax and St Margarets radars were used with MTI, the Barrington and Sydney radars without MTI. Care was taken to avoid or compensate for changes in radar sensitivity (Richardson, in press).

2. The amount of migration was recorded on a 0 to 8 ordinal scale (Richardson, in press). The terms 'light', 'moderate', and 'dense' used in this paper refer to density levels 2, 4, and 6 or more respectively.

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coast of eastern North America. However there was considerable variation between days and between different birds on the same day.

Birds flew unhesitatingly over water from Prince Edward Island to eastern New Brunswick, from Newfoundland to eastern Nova Scotia, and from western Nova Scotia across the Gulf of Maine to New England. Some even reached eastern New Brunswick by flying across the Gulf of St. Lawrence. As in spring, nocturnal migrants did not concentrate or turn at coastlines. However, by day concentrations along the shores of Nova Scotia and New Brunswick were common, and diurnal migrants often did change course at or near coasts.

Reverse migration — While the densest movements were directed to the SW, movements to the N-ENE were also very common. Such northeastward movement might be called reverse migration relative to the dense SW flights. In contrast to the often intense SW movements, these reverse flights were rarely of more than moderate density. Reverse movements from New England over the Gulf of Maine to Nova Scotia (Fig. 6 and 8) and from Nova Scotia over the Cabot Straight to Newfoundland were common.

The radars revealed nothing about the species composition of these reverse flights except that both passerines and non-passerines were involved. However the reverse movements presumably include many of the southern vagrants that reach the Maritimes in autumn.

Offshore departures — In addition to the dense SW movements and the less dense reverse flights, movements to the SE and were also very common. Both passerines and shorebirds were commonly involved. The same movements have been reported from New England (Drury and Keith, 1962) and New Jersey (Swinebroad, 1964). In the autumns of 1970 and 1971 I have recorded these birds as they reached Puerto Rico, 1800 miles south of Nova Scotia.

In Nova Scotia the shorebirds usually moved ESE, SE or SSE. They flew fast and high both by day and by night. The passerines departed only at night, and flew SSE, S or occasionally SSW. They flew at slower speeds and lower heights than the shorebirds. Indeed, on many occasions passerines were flying in all directions between SSE and W with no clear split between coastal and offshore movements. This severely complicates analysis, since it becomes impossible to decide if the intermediates are coastal migrants flying unusually far offshore, offshore migrants flying unusually close to the coast, or some species which always takes this intermediate course. Without such knowledge it is impossible to evaluate the orientation of the birds.

Most of the passerines and the shorebirds departed from areas well inland from the coast. Many departed from New Brunswick, flew over the Bay of Fundy and Nova Scotia, and then set out over the ocean without pausing. Others departed from Maine, flew by within sight of the western end of Nova Scotia, and continued offshore. On October 12, 1970 (Fig. 5), the St Margarets radar revealed that SE shorebird movement was well-developed as far inland as eastern New Brunswick and Prince Edward Island, where substantial numbers of flocks were flying at altitudes up to 15,000 ft.

The density of the offshore shorebird movements was usually quite light and it never exceeded moderate. The southward passerine flights were often much denser, although rarely as dense as the heaviest SW passerine flights. Nevertheless, during four seasons of study I recorded several southward passerine departures fully as dense as the densest SW movements.

Occasionally I have recorded birds heading east far off the south shore of Nova Scotia. These flights usually occurred with strong SW winds. Drury and Nisbet (1964) recorded similar flights near Cape Cod, and suggested that these were waterbirds that winter off the coast, and landbirds on reversed migration. The fate of the landbird component in these eastward movements is unknown. Many move far offshore with no evidence of turning back to land. Such flights may include some of the North American birds that frequently reach Europe (Sharrock, 1971).

Dawn reorientation — Birds which depart from Newfoundland or Nova Scotia after sunset and move SSW or SW during the night are likely to be well offshore at dawn. After nights of SW migration the Barrington and Sydney radars usually detected birds approaching land from the southeast. The birds turned from SW to W, NW or even N shortly before sunrise. At least some of these birds climbed to higher altitude at about the same time as they changed direction. Because they usually continued to arrive from the SE until noon or later, it is clear that most must have turned to the NW when out of sight of land. Some continued NW after they reached the coast.

Because of the NE-SW alignment of the coast, flight to the NW would be most likely to get a bird back to land if it found itself over water at dawn. This phenomenon appears very similar to the 'dawn ascent and reorientation' seen over the North Sea by Myres (1964) and others. There have been many visual observations of normally-nocturnal migrants flying back to the east coast of North America after dawn (Bagg and Emery, 1960; Baird and Nisbet, 1960). My data indicate

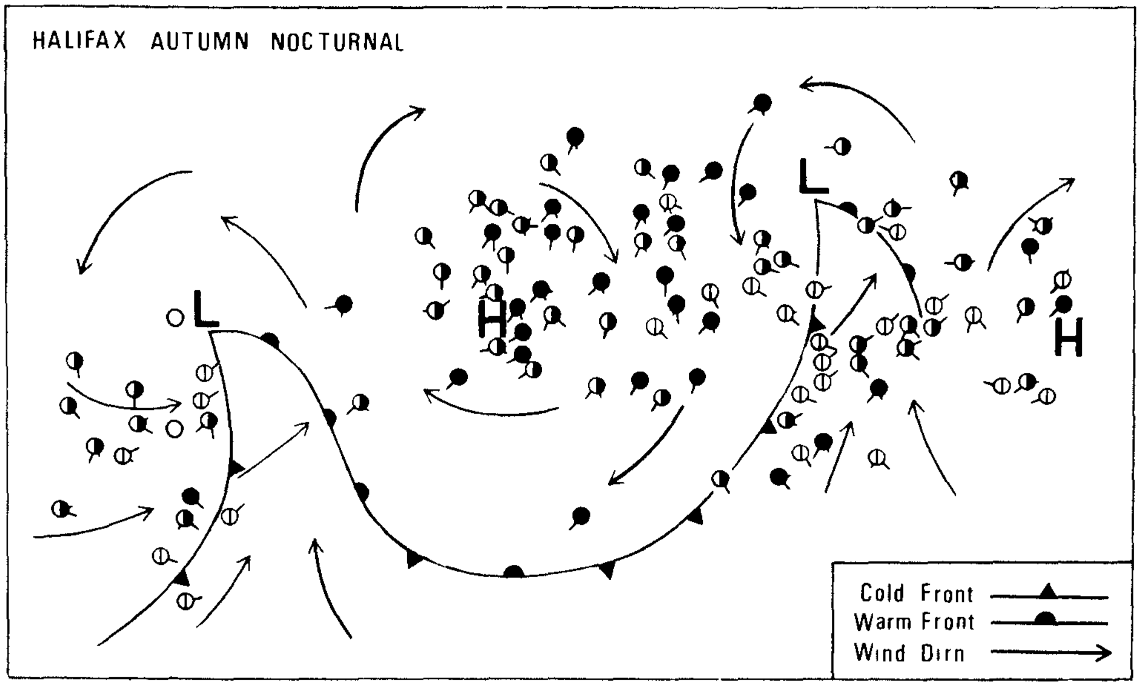


Figure 1. Density and direction of nocturnal migration near Halifax, Nova Scotia with different synoptic weather situations, Sept. - Nov. 1965 and 1969 plus Aug. 1970. Each point represents one night of radar observations at Halifax. A generalized weather map was drawn showing most of the common spatial relationships among pressure systems, fronts and wind direction. I examined the actual weather map for each evening, and noted the pressure systems, fronts and wind direction near Halifax. Then without knowledge of the intensity or direction of migration on that night I selected the location on the generalized map which best represented the position of Halifax relative to the actual synoptic features. There I placed a point representing the density and direction of migration one hour after sunset. The density was plotted as below normal, normal or above normal for that part of the season (open, half-filled and solid circles respectively). I used a 'moving-percentile' technique to determine the density categories (Richardson and Gunn, 1971). The arrows on the data points indicate the modal directions of migration. When there was more than one mode, secondary modes were shown by shorter arrows. On evenings when an appropriate map location could not be located, no point was plotted.

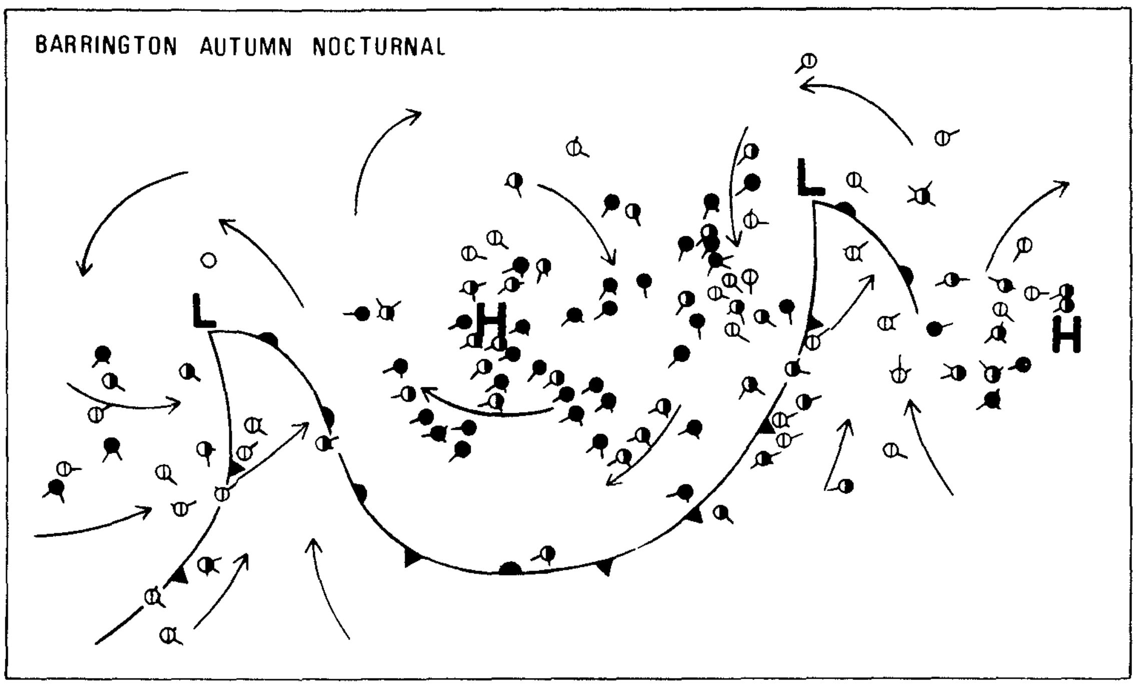


Figure 2. Density and direction of nocturnal migration near Barrington, Nova Scotia with different synoptic weather situations, Sept. - Nov. 1970 and Aug. - Nov. 1971. See legend to Figure 1.

that the phenomenon is common and that it includes high- as well as low-flying birds. Furthermore, it usually involves birds that flew SSW or SW at night, not those that flew SE or S. After nights with dense SE or S movement and no SW movement, I saw virtually no NW movement back to land.

HEIGHTS

The heights of autumn passerine and waterfowl migrants in the Maritime provinces were similar to those in spring (Richardson, 1971): the modal height at night was almost always below 2000 ft., and most of the individual birds were below 4000 ft. However there were usually a few individuals up to 7000 ft. The birds climbed rapidly early in the night, flew level for several hours, and then began to descend after midnight.

The shorebirds were flying much higher. When starting out from Nova Scotia over the ocean towards the West Indies, their average height was usually 4000 ft. or more, and on several occasions I found average heights of 11-13,000 ft. During these flights individual flocks were usually recorded up to 15,000 ft., and occasionally to 18-21,000 ft. Many of the shorebirds were already very high while they were still overland. Nisbet (1963) has recorded similar high movements of shorebirds heading SE from Cape Cod, and the birds arriving at Puerto Rico from the north are often at even greater altitudes (Richardson, in prep.).

The physiology of long-distance flight at these altitudes is of great interest. At 10,000 ft. over Nova Scotia in September, the temperature averages about 35°F.; the pressure and oxygen concentration are 70 per cent of the sea level values. At 18,000 ft. these values are reduced to 10°F. and 52 per cent respectively. While birds seem to be better adapted to high altitudes than are mammals (Tucker, 1968), other birds rarely fly as high as the birds over the western Atlantic. Thus flight at high altitudes must convey special advantages to these long distance migrants. Two possibilities are that flight in the cold air high up would minimize evaporative water losses (Pennycuick, 1969), and that stronger tailwinds are found high up than at lower altitudes. Both of these phenomena would serve to maximize the distance that a high-flying bird could travel.

WEATHER AND MIGRATION

As in spring, both the amount and direction of migration were strongly affected by weather. Fig. 1 and 2 summarize the four seasons of nocturnal data from central and western Nova Scotia. Fig. 3-10 show specific examples of weather and the direction of day-time migration over a wide area on eight successive days. **SW migration** was especially dense with N., NE and E winds. Such winds occur on the N, NW and W sides of low pressure areas and on the E, SE and S sides of highs. Near the centers of highs the winds are light and variable; dense SW migration often occurred in these circumstances as well. While SW migration was densest in the conditions described above, less dense SW movements occurred in many other situations. **Reverse NE migration,** on the other hand, occurred almost exclusively with S, SW, or W winds. Fig. 3 shows one occasion with widespread reverse migration. Such following winds are found on the E, SE or S sides of lows and on the W, NW or N sides of highs. In autumn as in spring (Richardson, 1971), the winds behind some of the cold fronts reaching the Maritimes are SW or W rather than NW or N. On these occasions reverse migration was common behind cold fronts (Fig. 1 and 2, left side). Richardson and Haight (1970) observed NE reverse Starling migration in Ontario with similar conditions. Thus, the passage of a cold front is not necessarily a sure sign that 'forward' rather than reverse migration will occur. **Offshore flights** to the SE or S were most common and densest when there were W or NW winds. Such winds usually occurred immediately after the passage of cold fronts and N or NE of high pressure areas (eg., Fig. 5). Like the SW flights but unlike the reverse NE flights, low density SE movement often appeared to occur without following winds (Fig. 1 and 2). However one must recall that the geostrophic winds shown in the figures are the probable wind directions at about 1000 to 5000 ft. The birds flying SE were mainly shorebirds, and many flew at altitudes far above 5000 ft. At their altitude the winds were probably closer to following than the figures often suggest.

Offshore movements were densest and most frequent in weather conditions intermediate between those producing NE and SW migration. Indeed, offshore flights often occurred simultaneously with either NE or SW flights, but rarely with both at once. Simultaneous SE shorebird movements and NE reverse flights often occurred when the winds were from the west. Such situations were found in the warm sector of some lows, behind some cold fronts, and north of some high pressure areas. Simultaneous SE or S offshore flights and SW coastal movements often occurred on the second night after the passage of a cold front. By this time the winds had usually shifted to the NW or N. When the winds shifted to NE or E as a high

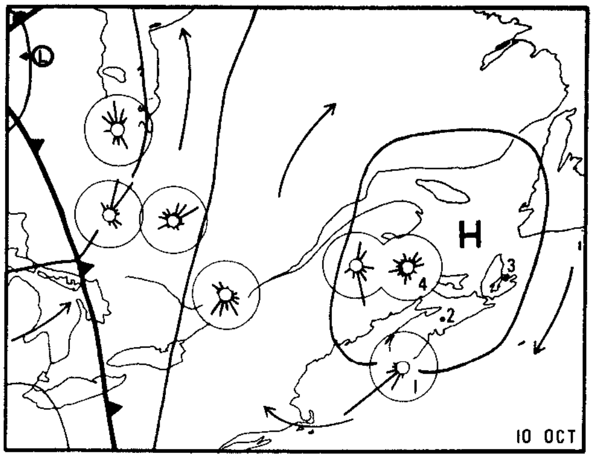
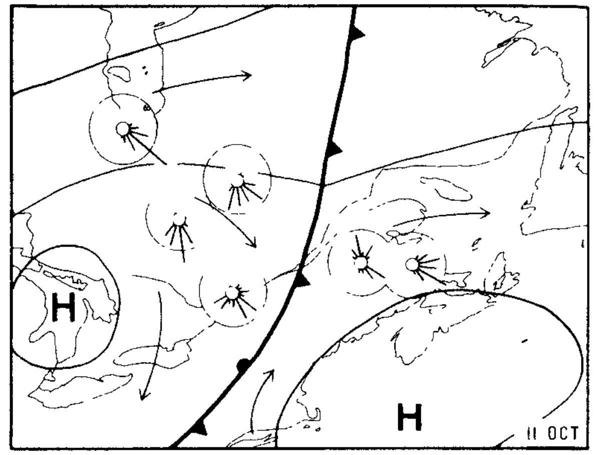


Fig. 3.



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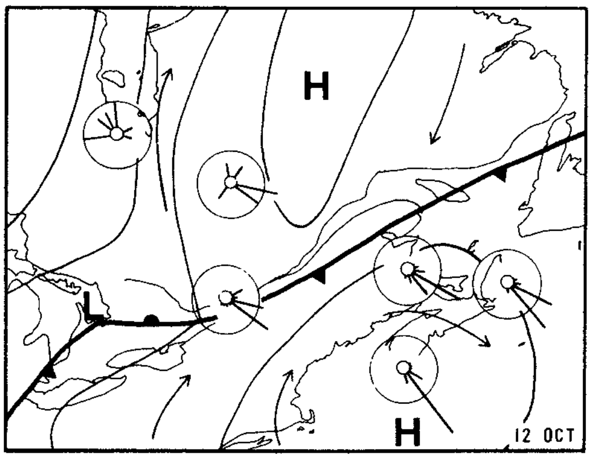

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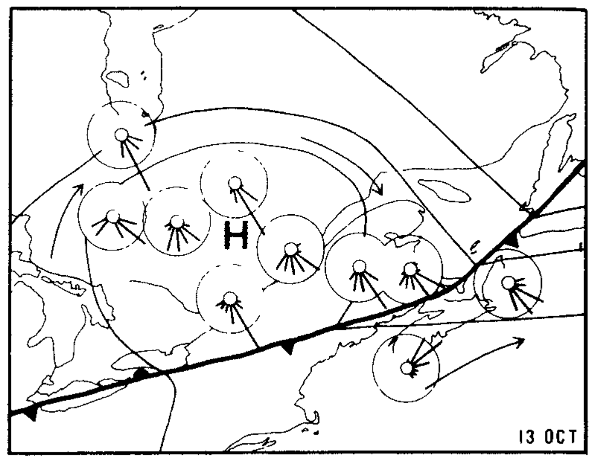

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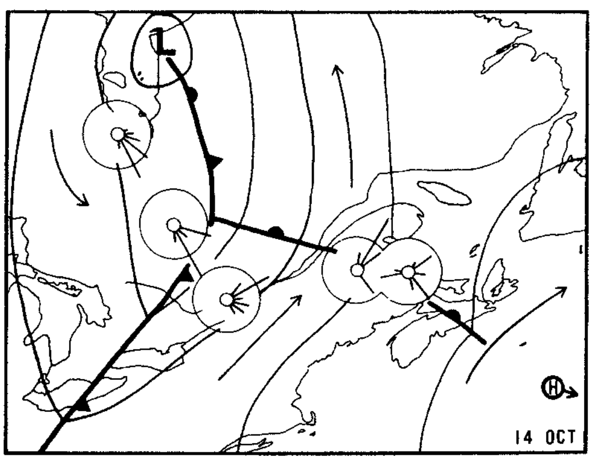

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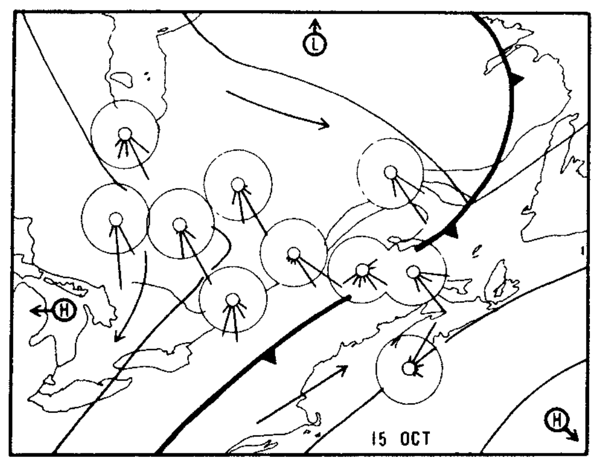
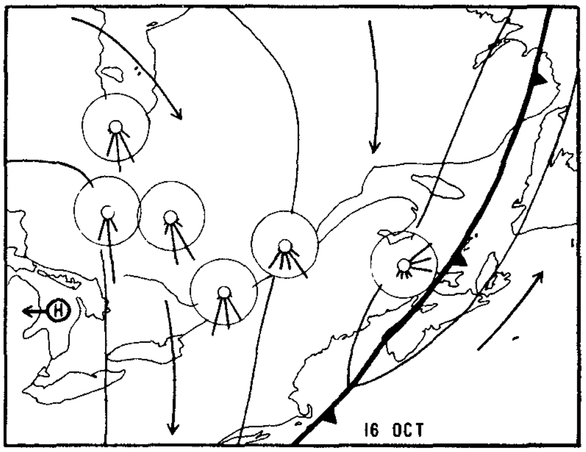


Figure 8.

Figures 3-10. Directions of diurnal migration at various sites in eastern Canada and Maine, 10-17 October 1970. In the vector diagrams the lengths of the lines represent the percentages of the birds moving in each direction. Weather maps for the corresponding times showing pressure systems, fronts, geostrophic wind directions and selected isobars are superimposed. Circled pressure system locations are off the map in the direction indicated. The sites numbered on Fig. 3 are: 1-Barrington, N.S.; 2-Halifax, N.S.; 3-Sydney, N.S.; and 4-St Margarets, N.B. The large circles indicate the approximate areas within which birds were regularly detected.



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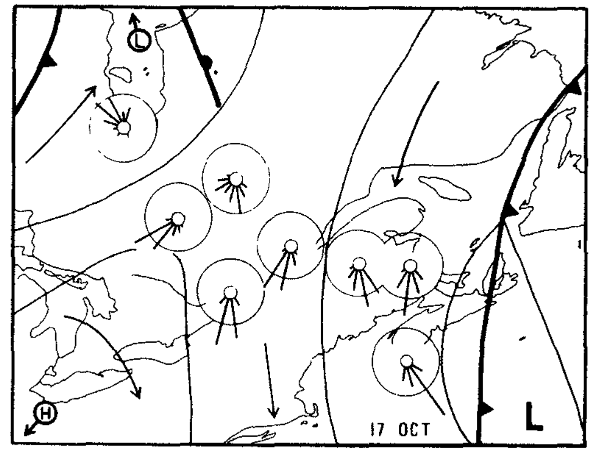

Figure 10.

moved past NW or N of the site, I usually recorded dense SW movement but little or no SE and S offshore flight.

Weather, the timing of take-off, and orientation — In some weather conditions offshore and coastal flights often occur simultaneously, while in other weather conditions only one of these types of movement is common (see above). Similarly SE offshore and NE reverse flights may occur together, but the densest of these two types of movement occur in clearly different conditions. Finally, there is a major difference between the weather conditions associated with the dense SW flights and those associated with the reverse flights. As suggested by Evans (1966), Nisbet and Drury (1967), Lack (1969) and Richardson and Gunn (1971), different populations of birds appear to be rather differently attuned to weather conditions, such that most fly with following winds relative to their own individual 'preferred' direction of migration.

Gauthreaux and Able (1970) have a somewhat different interpretation of such data. They have observed that passerines normally fly downwind. They conclude that passerines are somewhat selective about the weather conditions with which they fly, but that once aloft they fly downwind regardless of wind direction. My data and those of several other investigators are similar to those of Gauthreaux and Able. However, I have occasionally recorded passerine flights in mean directions other than downwind, even on occasions when the winds were of moderate (10-15 mph) strength. Furthermore, on most occasions when the mean direction was downwind there were many individual passerines flying in directions 30° or more away from downwind. Thus, in accordance with Evans (1970) and Nisbet (1971), I do not conclude that passerines normally orient downwind. Instead, it seems that they have some 'perferred' direction, that they normally fly only when favorable weather for that direction of flight occurs, but that once aloft they usually attempt to fly in the 'preferred' direction even if that is not exactly downwind. The peculiar 'preferred directions' that often occur (eg., autumn reverse movements) remain to be explained. **Cold fronts** — Lowery and Newman (1966) have suggested that when a cold front passes after sunset but before midnight, considerable southward movement may occur ahead of the front. My data do not support this view. South or SW movements of above average density very rarely occurred early in the night ahead of advancing cold fronts (Fig. (1 and 2). As noted above, however, low density SE shorebird flights often did occur ahead of cold fronts (eg., Fig. 6, Sydney). Sometimes the shorebirds took off ahead of the front; at other times they took off behind the front but caught up and moved through it, and then continued flying ahead of it. When fronts passed after the normal take-off time but before midnight, I usually saw low or moderate density NE or SE movement (or both) ahead of the front early in the night. After the front passed, the SE movement usually increased in density. In addition, if the winds behind the front were SW or W, the NE movement usually continued and little or no S or SW movement appeared. If the winds were NW or N behind the front, dense S and occasionally SW passerine flights normally appeared. These birds apparently took off behind the front well north of the radar site soon after sunset, followed the front southwards, and moved into the radar coverage area behind the front later in the night while the front was passing the radar site.

A strong cold front crossed eastern North America between October 14 and 17, 1970, and then moved offshore. Figures 7-10 show the radar view of widespread diurnal migration behind the front. The pat-

terns on the corresponding nights were similar, but with more birds in the air. Field observers recorded bird movement through most of eastern North America behind the front [*Am. Birds*, 25(1)].
E. On the 18th, I recorded with radar one of the densest movements of the season arriving at Puerto Rico from the north. Most of these birds presumably departed from the eastern U.S. with NNW winds behind the front on the night of October 16-17. I recorded few birds moving offshore from southeastern Canada that night since the frontal rain had not yet stopped.

HURRICANES

When hurricanes reach the Maritime provinces after moving up the east coast of the U.S., a variety of unusual birds are usually reported (Tuck, 1968; Mills, 1969). Laughing Gulls and Black Skimmers, species which rarely occur in the Maritime provinces (Tufts, 1962), become especially common. Until now radar observations of birds in hurricanes have not been reported.

On September 14, 1971 the remnants of Hurricane Heidi, by this time reduced to a strong low pressure area, moved north over the Gulf of Maine and then inland over Maine. Western Nova Scotia experienced rain and strong southerly winds as the low approached. The rain stopped by mid-morning but south winds of 35-45 mph continued all day. Using the Barrington radar, I recorded a moderately heavy movement of strong flock-type echoes approaching southwestern Nova Scotia. They moved very rapidly NW-N in the early morning and gradually shifted to N-NE later in the day. These flocks were at heights of 0 to 6000 ft. While the ground speeds of the birds were quite high, the air speeds were very low. For example, the ground speeds at noon averaged 49 mph while the tailwinds averaged 42 mph. Thus the birds were actually flying at only a few miles per hour. They were spread uniformly over the whole southern half of the Barrington display, an area over 140 miles wide. Some flocks continued inland; others disappeared (presumably having landed) at the coast.

This movement differed from a typical reverse flight in three ways: (i) There were many more birds than are usually found in reverse flights, (ii) the birds moved much faster than normal, and (iii) the mean direction of movement in the morning was NNW and later N and NNE, whereas reverse flights from New England to western Nova Scotia usually move NE. Since there is no land south of Nova Scotia until one reaches the West Indies, these birds presumably were swept counterclockwise around the hurricane.

CONCLUSIONS

The observations reported here provide new information about the patterns and timing of migration in southeastern Canada. Of special interest are the observations of frequent offshore departures, of reverse migrants, of birds in a hurricane, and of the difference in response to weather by offshore and coastal migrants. While orientation has not been discussed in detail, the relationships between flight directions and wind direction plus the observations of a dawn reorientation are significant. As such observations accumulate, we become more and more aware of the complexity of birds' orientation systems.

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