FALL MIGRATION OF SHARP-SHINNED HAWKS

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This paper is an analysis of data on the migration of Sharp-shinned Hawks (*Accipiter striatus*) recorded at the Cedar Grove Ornithological Station in the autumns of 1952 through 1964. Particular emphasis is placed on: (1) the time of occurrence of the migrations, (2) the temporal distribution of age classes during migration, (3) weather correlations, including a discussion of the structure of updrafts, and (4) the origins and destinations of the migrants observed at Cedar Grove.

The station is located on the western shore of Lake Michigan about 40 miles north of Milwaukee, Wisconsin. A detailed description of the area can be found in Mueller and Berger (1966). A general description and analysis of hawk migrations at Cedar Grove is given in Mueller and Berger (1961). An essentially dawn-to-dusk watch for migrating hawks was maintained on 915 days in the autumns of 1952 through 1964. Hawk traps were operated on most of these days, and on many days some of the observed migrants were trapped and banded. Observations often became sporadic on days with little or no migration; periodic watches were made with sufficient frequency to insure that few hawks passed unseen on any given observation day. Most of the hawks could be observed easily with the unaided eye, but 7 and 10 power binoculars and a 30 power spotting-scope were used when necessary, both for surveillance and as an aid in identification. In most years observations were conducted at the station on essentially every day from late August until at least late October. In 1952, 1956, and 1957 we sometimes left the station during periods of poor weather.

A total of 17,628 Sharp-shinned Hawks was observed and 2,052 were trapped, banded, and released. The species has been recorded at Cedar Grove only as a migrant. Sharp-shinned Hawks occur only rarely in summer or winter in southern Wisconsin. Our earliest "autumnal" record of a Sharp-shinned Hawk at Cedar Grove is 13 August; the latest date on which we have observed this species is 6 December. Most of the hawks were seen in the period between 10 September and 20 October (Fig. 1). There are three peaks in occurrence within the period: two in mid- to late September and one in mid-October. However, the migrations of all species of hawks are highly correlated with weather conditions, and the temporal distribution of weather conditions must be taken into account in any attempt to determine the periodicity of migration.

At Cedar Grove major fall hawk flights usually occur when the weather map has the following characteristics: (1) a low pressure area to the north-east and high pressure to the southwest of Cedar Grove; (2) the isobars lie across Wisconsin on a northwest-southeast diagonal, and (3) a cold front lies somewhere to the south and east (Class A weather of Mueller and Berger, 1961). However, Class A weather can occur without a concurrence of a major flight of Sharp-shinned Hawks (Fig. 1). Within the period 10 September through 20 October there is only one marked peak in the weather histogram; this coincides with one of the peaks in the hawk histogram. The remaining two peaks in the occurrence of Sharp-shinned Hawks, as well as the low point in occurrence in early October do not coincide with the peaks and low points in the distribution of Class A weather (Fig. 1). The occurrence of major flights, those days on which more than 100 Sharp-shinned Hawks were seen, closely resembles the distribution of the average number of hawks observed; and, similarly, seems to show two peaks which occur semi-independent of the distribution of weather (Fig. 1).

The age ratio of birds that were trapped indicates that immature birds predominate early in the season and that adults predominate late in the season. After 30 October very few Sharp-shinned Hawks are seen or trapped; many of these very late birds are immatures. Thus, there appear to be two peaks in the fall migration of Sharp-shinned Hawks at Cedar Grove: one in mid-September, composed mostly of immature birds, and one in mid-October, composed largely of adults.

WEATHER CORRELATIONS

The four most important meteorological factors associated with the fall migration of Sharp-shinned Hawks at Cedar Grove are probably (1) wind direction and velocity, (2) cold fronts, (3) the decrease in temperature concomitant with frontal passage, and (4) sunshine. The correlations of weather with migration presented in Figures 2, 3, and 4 are based on data from 29 August through 28 October of the years 1958 through 1963, inclusive, a total of 352 observation days.

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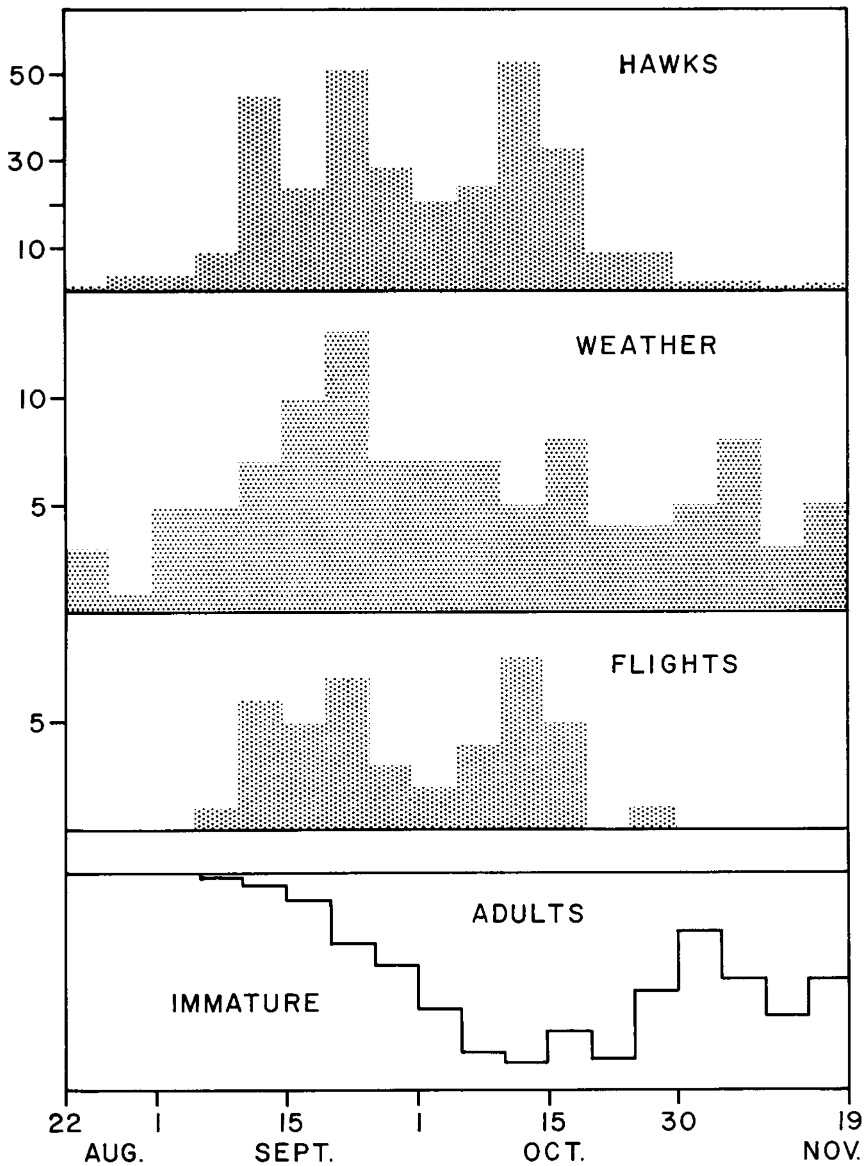
FIG. 1. Temporal distribution of Sharp-shinned Hawks, suitable migration weather, major hawk flights, and age ratio; for the years 1952 through 1964. The abscissa indicates calendar date; the data are grouped in five-day intervals and each bar thus represents five calendar days and from 21 to 64 observation days. Hawks: the mean number of Sharp-shinned Hawks observed per day. Weather: the total number of days having Class A weather (see text). Flights: the total number of days on which more than 100 Sharp-shinned Hawks were observed. The lower histogram indicates the age ratio of the birds that were trapped.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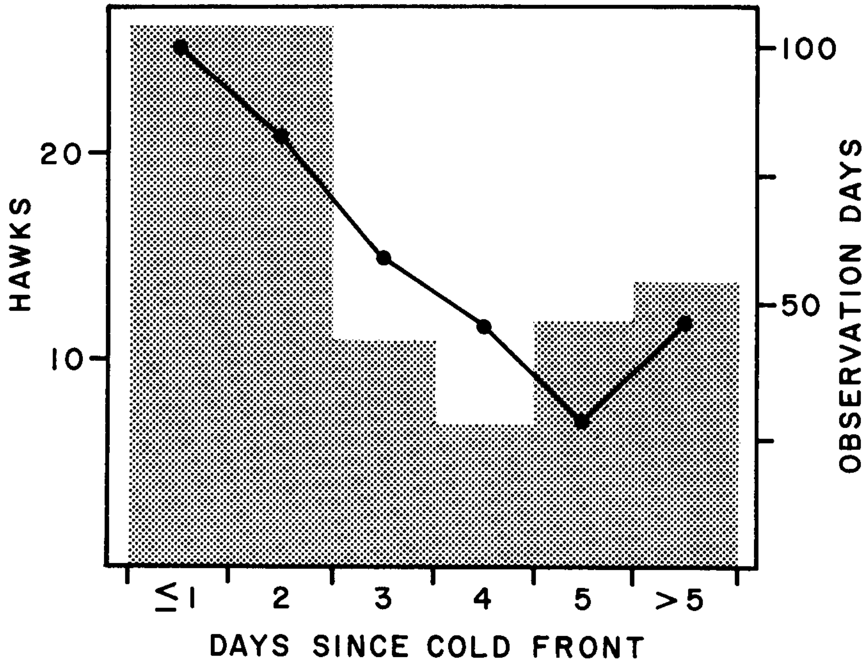

FIG. 2. Sharp-shinned Hawk migration in relation to time of passage of cold fronts. The bars indicate the mean number of Sharp-shinned Hawks seen per day, the points and line the number of observation days on which each bar is based.

Cold fronts.—The time of passage of cold fronts at Cedar Grove was estimated by examination of the U. S. Weather Bureau publications, *Daily Weather Map, Local Climatological Data,* and *Local Climatological Data Supplement* for Milwaukee, Wisconsin, and from uninstrumented observation at Cedar Grove. The mean time interval between cold fronts was 3.8 days and the maximum interval was 9 days during the six autumn study-periods. More than 39 per cent of all the Sharp-shinned Hawks observed migrated over Cedar Grove within one day after the passage of a cold front, and a total of 72 per cent passed within two days of frontal passage. The mean number of Sharp-shinned Hawks observed per day dropped sharply on the third and fourth days after the passage of a cold front and then increased slightly five or more days after the frontal passage (Fig. 2). This increase in hawks observed when the interval between cold fronts is prolonged is apparently the result of birds crossing a slowly moving or stationary front and therefore occurring before an oncoming front rather than after the preceding one. Thus, most hawks migrate in the relatively cooler air behind

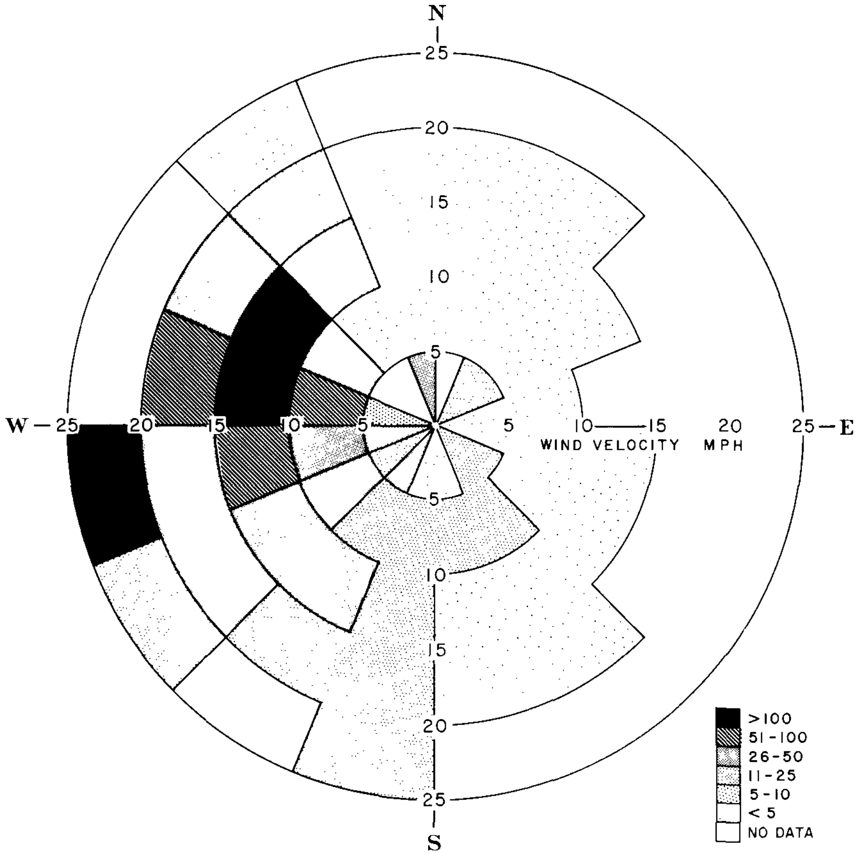

FIG. 3. Correlation of Sharp-shinned Hawk migration with wind direction and velocity. The wind data are the vector means of the 12 hourly readings taken between 0600 and 1700 hours at the U. S. Weather Bureau Station in Milwaukee, Wisconsin. The radial lines enclose 22.5° increments of mean wind vector-directions (e.g. all mean winds between W and WNW). The concentric circles enclose five mph increments of the vector-mean velocity. The intensity of shading within a given segment of the graph indicates the mean number of Sharp-shinned Hawks seen per day under the indicated conditions of wind direction and velocity. For example, a mean of more than 100 Sharp-shinned Hawks per day was observed on those days having a mean wind vector lying between W and WSW in direction and 20 to 25 mph in velocity.

a cold front, and a few cross slowly moving or stationary fronts into the relatively warmer air preceding the front.

Wind.—More than 93 per cent of the Sharp-shinned Hawks observed at Cedar Grove occurred on days when the mean diurnal wind was westerly.

The greatest mean number of hawks per day was seen when the mean diurnal wind was quite strong and had a marked westerly component (Fig. 3). Westerly winds drift southbound hawks eastward until they encounter the west shore of Lake Michigan (Mueller and Berger, 1961). Hawks are reluctant to fly out over the lake, and they tend to follow the leading line formed by the shore of the lake. A concentrated stream of migrating hawks results from the interaction of wind drift and the leading line. A detailed discussion of these phenomena can be found in Mueller and Berger (1967). Few hawks were seen on days when easterly winds prevailed. Easterly winds apparently drift birds away from the lakeshore (Mueller and Berger, 1961).

The wind usually has a northerly component after the passage of a cold front, although occasionally the winds are WSW, or more rarely SW, after frontal passage. Thus, the occurrence of some massed migrations on WSW winds is not surprising. However, the occurrence of migrating hawks on SSW, S, and even SE winds as compared with the paucity of migrating hawks on N and NNW winds is interesting (Fig. 3). The action of wind drift in NNW winds may be considerably less than in SSW winds. Northerly winds speed the southward passage of the birds allowing less time for drift while southerly winds slow the southward progress permitting wind drift to affect the bird for a longer period. Birds fly higher in a tail wind and exhibit less of a tendency to follow leading lines than in a head wind, when they fly lower (Mueller and Berger, 1967). When the wind is southerly at Cedar Grove there is a local tendency for the wind to blow in off of Lake Michigan, giving the wind in the immediate vicinity of the lake an easterly vector. In the warmer air mass usually associated with southerly winds, the air over the lake is often cooler than that over the land. When this cooler air blows in over the warmer land, displacing the warmer air, a line of updrafts paralleling the lake may be created, and, as we will show later, hawks apparently utilize updrafts. Once a hawk has found these updrafts, it might be induced to stay in the updraft zone, and thus fly along the lakeshore. In the cooler air mass usually associated with northerly winds there is little difference in temperature between the air over the lake and that over the land. Under these conditions we would expect about as many updrafts at any inland locality as we would along the lakeshore and, hence, no concentrations of hawks.

Temperature change.—In view of the correlation of the migration of Sharp-shinned Hawks and the recent passage of cold fronts, it is not surprising to find that the migrations correlate rather well with a recent drop in temperature (Fig. 4). In an earlier paper on the influence of weather on the migrations of all species of hawks (Mueller and Berger, 1961), we

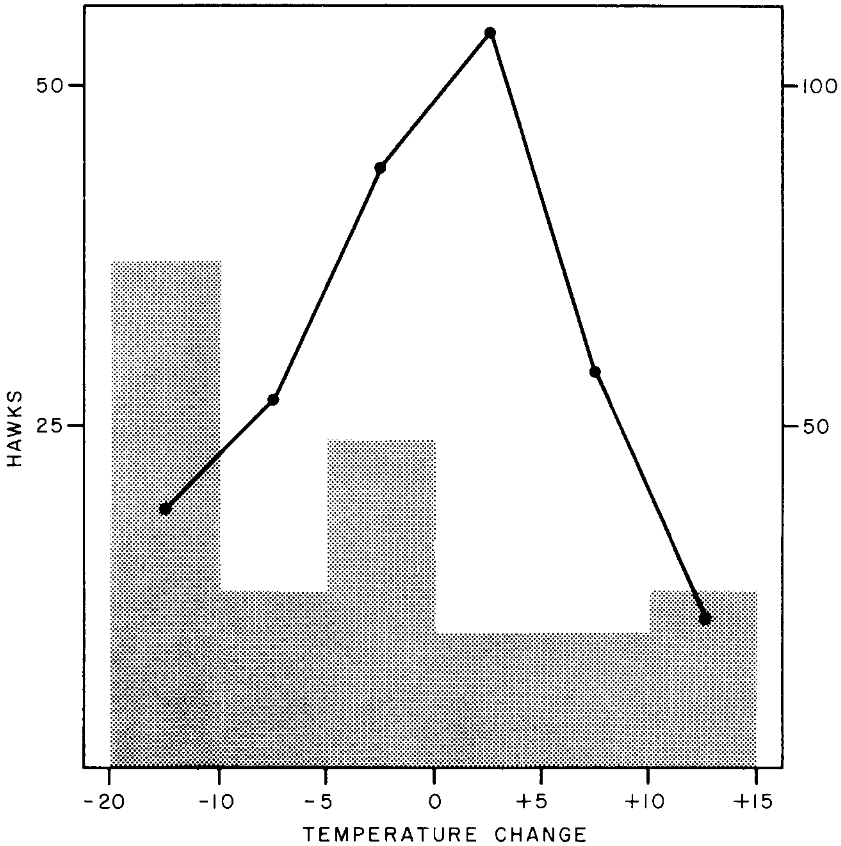

FIG. 4. Temperature change and the migration of Sharp-shinned Hawks. The bars indicate the mean number of hawks observed and the points and line the number of observation days on which each bar is based.

attempted to correlate migration with a variety of temperature measurements and changes in temperature. Of these attempts, perhaps the best correlation was obtained by use of the departure of the mean 0030 (CST) temperatures for Duluth, Minnesota, Wausau, Wisconsin, and Escanaba, Michigan, from the corresponding data of the previous day. This measurement represents an index of temperature change in the probable area of immediate origin of the migrations observed at Cedar Grove. This temperature change was used in compiling Figure 4 and is the only datum used in temperature analysis in this paper. More than 69 per cent of the Sharp-shinned Hawks observed at Cedar Grove occurred when the area temperature had dropped during

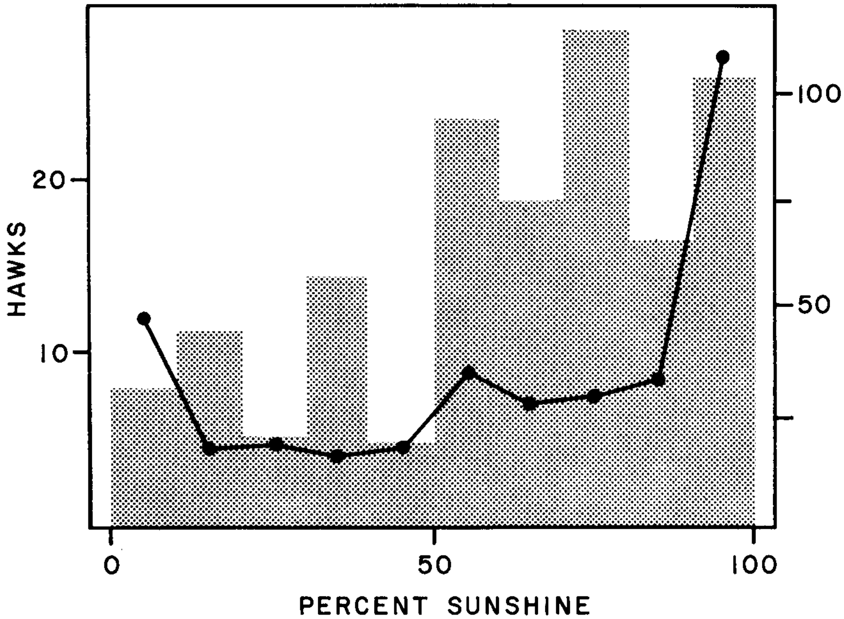

FIG. 5. The migration of Sharp-shinned Hawks in relation to sunshine. The incidence of sunshine is expressed in terms of the per cent of the possible sunshine. The bars indicate the mean number of hawks observed and the points and line indicate the number of observation days on which each bar is based.

the previous 24 hours. The greatest number of hawks per day was observed when there was a marked decrease in temperature, although many hawks were seen when the temperature dropped only slightly (Fig. 4). The slight increase in the number of birds observed when there was a marked increase in temperature may be attributed, largely, to those birds that crossed slow moving or stationary cold fronts into the warmer air mass preceding the front.

Sunshine.—More than 84 per cent of the Sharp-shinned Hawks observed at Cedar Grove occurred on days when the sun was shining at least half of the time between sunrise and sunset (Fig. 5). Insolation heats the ground, and the warmed ground heats the air immediately above. Warm air rises, creating updrafts. The cooler air and the usually partly cloudy or clear skies in the air mass following a cold front provide optimal conditions for updraft formation.

UPDRAFTS

In the lower layers of the atmosphere updrafts can largely be placed into two classes: (1) mechanical updrafts caused by the vertical deflection of the horizontal wind, as on a mountain ridge, and (2) thermal updrafts, the rising of warmer, less dense air through cooler, denser air. The structure of thermal updrafts varies with the temperature difference between the air and the underlying surface, the roughness of the surface, and the wind velocity. The temperature responses to insolation of ground surfaces and their heat capacities also vary widely. Little is known about the structure of updrafts under these varying conditions.

Earlier theories held that thermal updrafts were in a columnar form. Later theories held that convection over a terrestrial surface was in the form of discrete bubbles (Ludlam and Scorer, 1953). More recently, Cone (1962) theorized, partly on the basis of observations of soaring birds, that updrafts over a terrestrial surface take the form of discrete vortex rings. In addition to the upward movement of such a vortex ring, the air on the surface of the ring circulates in such a way that it moves upward on the inside of the ring and downward on the outside. Birds remain airborne by soaring in circles in the upcurrents on the inside of the ring. Cone (1962:190) observed that individuals of a group of soaring birds always circle at about the same altitude, and he offers this as partial evidence in proof of his vortex ring hypothesis. However, on many occasions we have observed Broad-winged Hawks (*Buteo platypterus*) soaring in circles in a column, with birds more or less uniformly distributed at all altitudes in the column. On a few occasions the height of the column of circling birds, from the lowest birds to the highest, exceeded 1,000 feet. The updrafts must have been in the form of a column, or in the form of a continuous chain of bubbles or vortex rings. Further systematic observations of circle soaring in various localities and under a variety of conditions are needed.

Our observations also suggest that still other forms of updrafts may exist. The great majority of Sharp-shinned Hawks that migrate over Cedar Grove do not soar in circles. The typical mode of flight consists of a few flaps of the wings followed by an extended glide, all in an approximately straight line. The birds appear to be utilizing updrafts since they often rise 25 to 50 feet with little or no flapping of wings. On windy days even the larger hawks and vultures, which normally soar in circles, are seen to pass over Cedar Grove in a more or less straight line. Many of these birds fly for hundreds of feet without flapping and without losing altitude. Hankin (1913) lists many similar observations of rectilinear soaring or gliding by Indian birds of prey.

Woodcock (1942) studied updraft structure over the North Atlantic Ocean by watching the soaring of gulls. Gulls soared in circles when the surface water temperature was at least 2 degrees C higher than that of the overlying air and the wind velocity was less than 15 mph. When the air–water temperature difference was at least 4 degrees C and the wind velocity was between 15 and 28 mph the gulls soared in straight lines, headed upwind. No soaring was observed at wind velocities greater than 28 mph, presumably because updraft structure was disrupted or updrafts were of insufficient lateral extent to support gulls. He hypothesized that under these conditions of moderate to high winds the thermal updrafts were in the form of longitudinal, vertical sheets, oriented up- and downwind. These updraft sheets are probably the rising portions of horizontally oriented helical vortices, convection cells in which the long axis is parallel to both the wind and the surface of the earth. Similar convection cells have been observed in a lake (Langmuir, 1938) and in the laboratory (Phillips and Walker, 1932; Graham, 1934). An ocean surface is flat and is uniform in temperature. Land surfaces are irregular, and the surface temperature often varies greatly over a distance of a few feet. Convection patterns over a land surface undoubtedly differ from those over the ocean. However, the presence of a strong horizontal wind certainly must affect the structure of updrafts over a land surface. In the absence of evidence to the contrary, we suggested in an earlier paper (Mueller and Berger, 1961) that updrafts over a land surface, under conditions of high land–air temperature contrast and winds of 15 to 30 mph, might assume a form similar to that described by Woodcock (1942). The irregularities in topography and temperature of the ground, acting individually or in combination, might produce a quasi-permanent distribution of updrafts over a land surface in the presence of moderate to high winds. Mechanical updrafts would remain in the same place as long as the wind remained constant in direction and velocity. Areas with high surface temperatures would remain largely unchanged as long as the amount of heat delivered to the surface remained unchanged. Thus, for periods up to a few hours the updraft distribution over a given area might vary only slightly.

We have often noted that most of the hawks observed at Cedar Grove in a given period of time appear to be following one or several invisible, three-dimensional paths through the air over the area. Many of the hawks change direction and altitude at the same points where previous hawks have altered course and altitude. Since the hawks do considerable gliding, this suggests that they are "following" an updraft pattern through the area. We do not know to what extent Sharp-shinned Hawks use such updrafts away from a leading line, but once they arrive at the western shore of Lake Michigan in the vicinity of Cedar Grove the hawks definitely appear to be using an updraft pattern that permits rectilinear gliding at low altitudes. Since most of the Sharp-shinned Hawks observed at Cedar Grove occur on days favorable for the formation of updrafts (Figs. 3, 4, and 5) and when moderate to strong winds are blowing (Fig. 2) it may be that most Sharp-shinned Hawks migrate when the updraft pattern is somewhat similar to that described by Woodcock (1942). However, Sharp-shinned Hawks occur at Cedar Grove on westerly winds, and increased wind velocities increase the effects of wind drift. With increased drift, increasing numbers of birds arrive at the leading line formed by the shore of Lake Michigan, and larger numbers of hawks are counted at Cedar Grove. Thus, most Sharp-shinned Hawks may migrate on days on which updrafts and strong winds occur, or the correlation of migration with strong winds at Cedar Grove may be purely the result of increased wind drift. We suspect that Sharp-shinned Hawks exhibit a greater tendency to migrate on windy days. Regardless of the structure of updrafts, our data indicate that most Sharp-shinned Hawks migrate on days when the weather conditions are conducive for the formation of updrafts. The cooler air, and the partly cloudy skies in the air mass following a cold front provide optimal conditions for the formation of updrafts.

EXTRAORDINARY MIGRATIONS AND WEATHER

In the autumns of 1952 through 1964 we have recorded 42 days on which more than 100 Sharp-shinned Hawks were observed at Cedar Grove. More than 400 Sharp-shinned Hawks were seen on only four days: 486 were observed on one day, 676 on another, and on each of two days extraordinary totals of more than 1,200 Sharp-shinned Hawks were seen. The latter two days, 15 September 1952 and 13 October 1955, were associated with a sequence of weather conditions that occurred only during the brief periods prior to and including these two days and not again during the 13 years of our study. The essential feature of the weather map at these times was a cold front extending from east to west, which penetrated into northern Wisconsin, stalled, and then retreated slowly to Lake Superior over a period of two or three days (Fig. 6). A second cold front, extending from north to south swept through the area three to five days after the first front and continued onward to the east and south (Fig. 6). The extraordinary flight in both cases occurred on the day after the second front passed Cedar Grove.

In both of these cases of extraordinary flights, we believe that it is probable that the Sharp-shinned Hawks began to migrate with the southward movement of the first cold front. When this front stalled, and subsequently retreated, a few hawks probably continued to migrate southward, but we suspect that most individuals soon ceased migrating. The weather situation thus deposited great numbers of hawks in northern Wisconsin and upper Michigan. The second cold front again initiated migration, and unusual numbers of hawks passed Cedar Grove.

TABLE 1
WIND DIRECTION AND VELOCITY AT 1200 HRS.

Date	Hawks**	U. S. Weather Bureau Station*				
		Dlh	LCr	SSM	GrB	Mke
12 Sept. 1952	31	S 10	SSW 8	E 6	SSW 11	ESE 15
13	87	ESE 12	S 12	SE 5	SSW 16	SE 13
14	285	WSW 25	NW 17	SSE 14	SW 16	SW 20
15	1219	WNW 20	WNW 20	NW 6	WNW 23	W 21
10 Oct. 1955	43	SSE 8	SSE 10	WSW 9	SW 20	SW 15
11	16	SSE 21	S 20	S 7	SW 17	SW 18
12	200	WNW 35	NW 22	ESE 12	WNW 22	WNW 23
13	1220	NW 23	NW 20	SSW 7	NW 22	WNW 21

* Duluth, LaCrosse, Sault Ste. Marie, Green Bay, and Milwaukee.
** Number of Sharp-shinned Hawks observed at Cedar Grove.

Table 1 presents the noon records of wind direction and velocity recorded by the U. S. Weather Bureau at Milwaukee and four selected points to the north and northwest during the two critical periods which ended with the extraordinary flights. On 12, 13, and 14 September 1952 the winds at noon at Sault Ste. Marie, Michigan, had an easterly component (Table 1). Birds flying over the isthmus between Lakes Superior and Huron would presumably be drifted westward and would have an increased probability of ending up on the western, rather than the eastern side of Lake Michigan. Those hawks that continued southward into Wisconsin encountered winds with a westerly component in the vicinity of Green Bay, Wisconsin, and presumably were drifted eastward to Lake Michigan. A few birds presumably continued to follow the leading line provided by the lakeshore on 12 and 13 September, even though the winds again became easterly in the vicinity of Milwaukee (Table 1). On 14 September the winds were westerly at both Green Bay and Milwaukee, and the daily count of Sharp-shinned Hawks increased accordingly. Noon wind recordings at Duluth, Minnesota, at the western end of Lake Superior, suggest that the winds in this area were not adequate to drift birds toward Cedar Grove until 14 September, when strong WSW winds may have provided for sufficient eastward drift (Table 1). At LaCrosse, approximately south of Duluth and west of Cedar Grove, winds had either a positive or neutral westerly component throughout the period (Table 1). The weather data thus suggest that hawks were trickling southward from the Sault Ste. Marie area toward Cedar Grove from 12 through 14 September 1952. The strong WSW winds at Duluth may have begun to add to this flow on 14 September. On 15 September strong westerly to

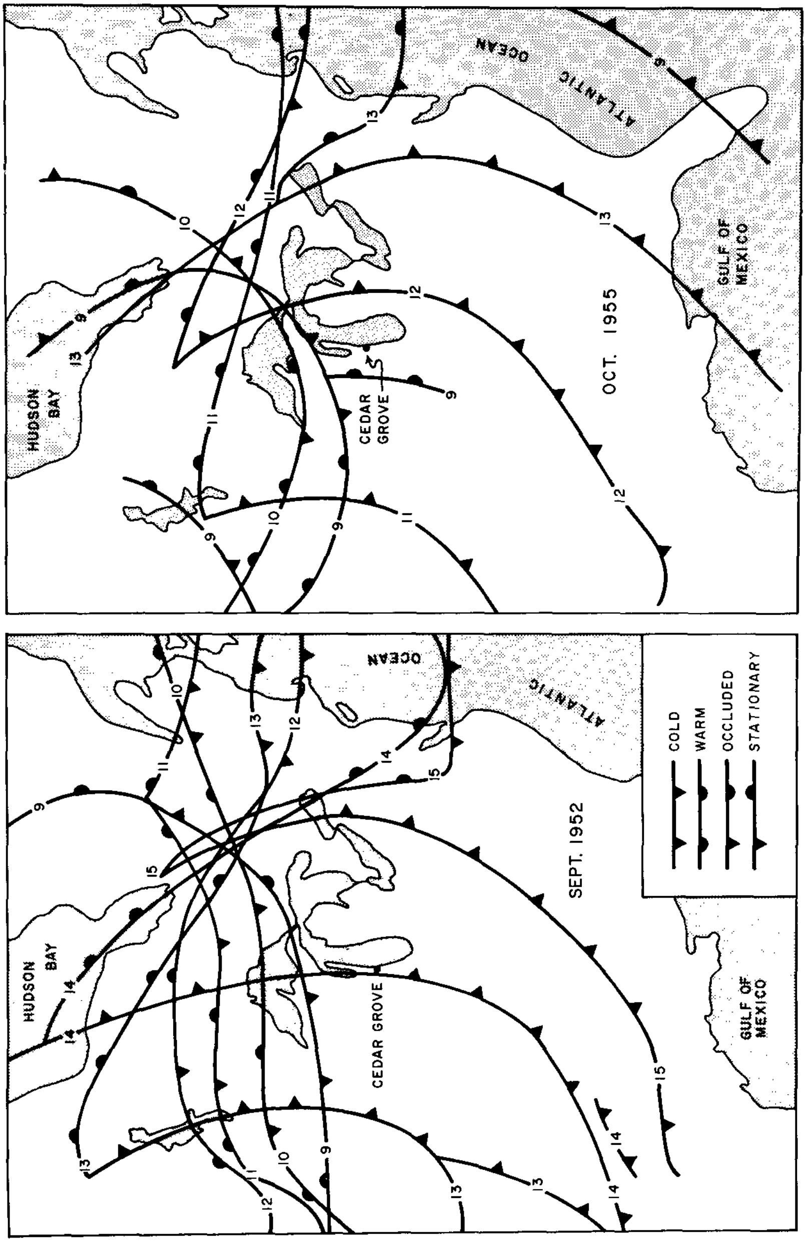

FIG. 6. Positions of fronts in the eastern United States at 1200 hours (CST) on each of several days. Left: 9 through 15 September 1952. Right: 9 through 13 October 1955.

northwesterly winds and optimal conditions for migration quickened the flow, resulting in a record count of Sharp-shinned Hawks at Cedar Grove.

The extraordinary flight of Sharp-shinned Hawks on 13 October 1955 was preceded by only slightly different wind conditions than that of September 1952. Winds with an easterly component at Sault Ste. Marie did not prevail until 12 October. As a result, hawks entering the Wisconsin area at Sault Ste. Marie may have contributed less to the flight of 13 October 1955 than that of 15 September 1952. The noon wind at Duluth on 12 October 1955 had an extremely high westerly component of more than 32 mph, and it is possible that birds entering Wisconsin in the Duluth area contributed greatly to the record flight observed at Cedar Grove on 13 October 1955. Winds were westerly at Milwaukee and Cedar Grove throughout the four-day period, providing good local conditions for the drift of birds to the shore of Lake Michigan (Table 1). On 12 and 13 October 1955 the westerly component of the wind was particularly high at Milwaukee, and other weather conditions were also optimal for migration. Thus, the spectacular flights of Sharp-shinned Hawks on 15 September 1952 and 13 October 1955 appear to be due to an unusual sequence and movement of fronts and to the temporal and spatial distribution of wind conditions in the area north of Cedar Grove.

RECOVERIES OF BANDED BIRDS

We know of 57 recoveries of Sharp-shinned Hawks banded in the vicinity of Cedar Grove (Fig. 7). Eighteen birds were recovered before 15 December of the same autumn in which they had been banded (closed circles in Fig. 7). The mean angle from Cedar Grove for this distribution of recoveries is about 10 degrees east of south. Fifteen birds were recovered during the winter (15 December through 15 March) immediately following the autumn in which they were banded (closed triangles of Fig. 7). The distribution of these recoveries has an average angle of about five degrees east of a line drawn south from Cedar Grove, an angle not significantly different from that of the autumn recoveries.

Both the autumn and winter recoveries show a marked change in mean direction with change in latitude. The 17 birds recovered north of the southern border of Tennessee and within five months of the time of banding have a geographic distribution which yields a mean angle of 18 degrees east of a line drawn south from Cedar Grove. The distribution of the 16 similar recoveries from south of the Tennessee border yields a mean angle of 7 degrees west of south, about 25 degrees farther west than the more northern recoveries. The prevailing winds during September, October, and November generally have a westerly component in the north central United

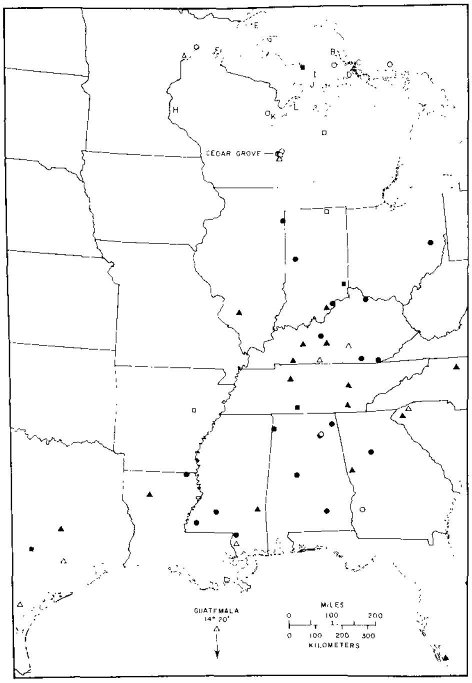

FIG. 7. Distribution of recoveries of Sharp-shinned Hawks banded at Cedar Grove during autumnal migration. Closed symbols indicate birds recovered less than one year after the time of banding; open symbols indicate birds recovered four seasons or more after the time of banding. Circles: autumn recoveries (1 September–15 December). Triangles: winter recoveries (16 December–15 March). Squares: spring recoveries (16 March–31 May). Other symbols indicate localities mentioned in the text.

States and an easterly component in the states bordering the Gulf of Mexico (U. S. Department of Commerce, 1964). The apparent tendency for hawks to move south-southeastward from Cedar Grove and then turn somewhat to the west in the southern United States may thus be nothing more than a result of wind drift. The above evidence suggests that the heading, or standard direction, of migration of the Sharp-shinned Hawks observed in autumn at Cedar Grove is approximately due south.

The eight birds that were recovered in winter a year or more subsequent to the time of banding add little to the above discussion except: (1) there is one far northern recovery, in the vicinity of Cedar Grove, and (2) there is one far southern recovery in southeastern Guatemala (open triangles of Fig. 7).

Six of the eight birds recovered in autumn one or more years after the autumn in which they had been banded are of considerable interest (open circles of Fig. 7). Four of these birds were recovered to the north of Cedar Grove, one at the western end of Lake Superior, two at the eastern end, and one just west of Green Bay. The distribution of these four recoveries suggests that Sharp-shinned Hawks observed at Cedar Grove during autumnal migration enter the Wisconsin area around both ends of Lake Superior, with possibly the majority entering through the Sault Ste. Marie region. Two birds were retrapped at the Cedar Grove Ornithological Station approximately one year after banding, indicating that individual birds occasionally occur at the same point on the migratory route in subsequent years. However, the recurrence at Cedar Grove of these two individuals can probably be attributed to a chance distribution of weather patterns which brought the birds to the same point on the migratory route in two consecutive years. We trap about 12 per cent of the Sharp-shinned Hawks we observe at Cedar Grove. If we assume a 50 per cent annual mortality for the combined sample of juveniles and adults, and that all survivors of the group of birds banded at Cedar Grove will recur there during the next autumn, we would expect to catch six birds for every 100 banded the previous autumn. We would expect to have recaptured 104 banded Sharp-shinned Hawks at Cedar Grove in the autumn subsequent to the year of banding. We would further expect additional birds to be recaptured two or more years after banding. The fact that only two birds have been recaptured suggests that individual Sharp-shinned Hawks do not follow the same migratory route year after year.

Two of the seven hawks recovered during the time of spring migration (15 March through 31 May) are of interest (squares in Fig. 7). These two individuals were recovered to the east of Lake Michigan, suggesting that migratory routes change with the season or that Sharp-shinned Hawks do not follow the same migratory route year after year. We have obtained only one summer recovery of a Sharp-shinned Hawk. This bird, banded as an adult on 17 October 1964, was found dead on 22 July 1965 at Fawcett, Alberta, about 1,500 miles northwest of Cedar Grove.

OTHER OBSERVATIONS OF HAWK MIGRATION IN THE UPPER GREAT LAKES AREA

Many of the hawks observed at Cedar Grove probably enter Wisconsin and upper Michigan by passing around the ends of Lake Superior. The spectacular flights at Duluth, at the western end of Lake Superior, are well known (Hofslund, 1954). (See point A in Figure 7. The parenthetical letters after other locations mentioned below also refer to Figure 7). Great numbers of hawks apparently also enter the United States at the eastern end of Lake Superior, but the flights are less well known because often the birds are not found in as concentrated a "flyway" as at Duluth. Some hawks cross Whitefish Bay to Whitefish Point (B) some 40 miles west of Sault Ste. Marie (C. Hawkins, pers. comm.). J. M. Speirs (pers. comm.) has observed a broad-front movement through the Sault Ste. Marie area (C). Concentrated hawk flights have also been observed on the north shore of Lake Huron (D) between Detour and the Pine River (K. Slater, pers. comm.).

Some hawks may cross Lake Superior. Concentrations of hawks occur in fall at Isle Royale (E) (Peet, 1909). Lesser concentrations occur on the Apostle Islands (F) (J. Keener, pers. comm.) and on the Keweenaw Peninsula (G) (Binford, 1965). The concentrations at the latter two points may be the result of the northbound wanderings of young hawks rather than overwater migrations. In spring hawks do depart in a northerly direction across Lake Superior from the tip of the Keweenaw Peninsula (Wood, 1933). On the south shore of Lake Superior, the Bayfield County peninsula, the Keweenaw Peninsula, and Whitefish Point all provide leading lines which tend to gather and direct hawks out over the lake. On the other hand, the leading lines of the north shore (except for the islands and peninsulas in the limited area north of Isle Royale) tend to lead birds to the ends of the lake. We suspect that the majority of the hawks involved migrate around, rather than across, Lake Superior in autumn.

We know little of what happens to the Duluth hawk flights after they pass south of Lake Superior. S. Robbins (pers. comm.) occasionally has seen hawk movements near Roberts, Wisconsin (H). The Sault Ste. Marie flights are somewhat easier to trace. Hawk movements have been observed both inland (I) and on the north shore of Lake Michigan (J) in Schoolcraft County, Michigan (K. Christofferson, pers. comm.; Beebe, 1933). C. Richter (pers. comm.) has observed hawk flights on the west shore of Green Bay (K) which in some instances correlated rather well with flights seen a day or so later at Cedar Grove. H. Wilson (pers. comm.) once saw migrating hawks at the northern tip of the Door County Peninsula (L), suggesting that some hawks may cross the mouth of Green Bay on the chain of islands stretching from Delta County, Michigan, to Door County, Wisconsin.

Some 20 miles south of Cedar Grove the volume of hawk migration appears to be reduced. Hawk flights are rarely observed in or about the city of Milwaukee, about 40 miles south of Cedar Grove. Near Racine, another 20 miles south, some hawk migration is again observed (M. Higgins, pers. comm.). Some migrating hawks are also seen near Zion, Illinois (J.

Weaver, pers. comm.), but south of this point we have no information concerning hawk flights. The number of hawks observed at the last two localities is usually not as great as at Cedar Grove.

To summarize these observations, hawk flights have been observed at both the east and west ends of Lake Superior. Some hawks may cross Lake Superior. Hawk flights have been observed at a number of points on the west shore of Lake Michigan. The volume of the flight varies as does the direction of the lakeshore, the topography, the incidence of urban and industrial areas, and the distribution of habitat types. Lack of reports from the areas between known hawk migration points does not imply that flights are lacking; too often it means that adequate observations have not been made. Many of the Sharp-shinned Hawks observed at Cedar Grove probably enter the United States at Sault Ste. Marie. Most of the rest of the hawks seen at Cedar Grove probably enter Wisconsin near Duluth.

SUMMARY

Daily counts of Sharp-shinned Hawks were conducted on 915 days in the autumns of 1952 through 1964. A total of 17,628 Sharp-shinned Hawks was observed and 2,052 were trapped, banded and released. There are two peaks in the autumnal migration, one in mid-September, composed mostly of immature birds, and one in mid-October, composed largely of adults.

Ninety-three per cent of the Sharp-shinned Hawks were observed on days with westerly winds, 72 per cent were recorded within two days of the passage of a cold front, 69 per cent were seen on days when the area temperature had dropped during the previous 24 hours, and 84 per cent were observed on days when the sun was shining for at least one-half of the time between sunrise and sunset. On the basis of these data we suggest that hawks fly when conditions are conducive for the formation of updrafts and that wind drift concentrates migrants along the leading line formed by the western shore of Lake Michigan. The flight behavior of hawks and the structure of updrafts is discussed in some detail.

An analysis of two extraordinary migration flights suggests that weather conditions hundreds of miles to the north may affect the numbers of birds seen at Cedar Grove.

The recoveries of banded birds, and observations of hawks at other points in the Upper Great Lakes region suggests that most of the hawks seen at Cedar Grove enter the area at the eastern and western ends of Lake Superior. The distribution of fall and winter recoveries suggest that the birds head approximately southward, are drifted eastward in the north and central portions of the eastern United States, and are drifted westward in the states bordering the Gulf of Mexico.

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