SPRING MIGRATION AND WEATHER AT MADISON, WISCONSIN[1]

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Only a small portion of the literature on the influences of weather on bird migration considers the recording of migration on the basis of quantitative day-to-day changes in the numbers of transient migrants at a given location. Ground counts if taken daily can be useful in providing information on the arrival and the departure of migrants, and on the attending weather conditions. Radar and moon watching techniques provide the best known approaches for obtaining quantitative data on migration in progress but often reveal little of the species involved and little of the points of inception and termination of migration waves.

During the springs of 1963, 1964, and 1966 daily counts of the grounded (or stopover) transient populations of night migrating passerines were conducted at Madison, Wisconsin. The influxes and departures revealed by these counts are examined in relation to general weather conditions and specific weather components.

METHODS

The data were obtained at a twenty-acre study area at Picnic Point on the University of Wisconsin campus on 45 days from 15 April to 29 May in 1963 and on 42 days from 15 April to 27 May in 1964. Also in 1964 migration data were collected on 37 days from 15 April to 21 May at a 4.5-acre study area in the Stevens Pond region of the University of Wisconsin Arboretum several miles south of Picnic Point. These data were pooled with the 1964 Picnic Point data. In 1966 data were gathered on 29 days from 15 April to 21 May at a 6.5-acre woodlot located about 5 miles southwest of Madison. All three study areas were dominated by deciduous trees and attracted roughly the same bird species. Because counts could not always be made every day and because day-to-day changes in numbers of observed migrants are used as a measure of migration, the number of units of usable data is reduced to 44 for 1963, 40 for 1964, and 20 for 1966 (total = 104).

All passerines that were identified by sight or call were recorded. Birds flying over were not included in the analysis. Counts were conducted in the morning hours, with a few exceptions. The study areas were covered systematically and intensively by slowly traversing the irregular network of trails. This method has been used effectively in similar studies by Bennett (1952), Dennis (1954), and others. The area and distance traversed were held essentially constant, although the time spent afield varied with bird densities. The figures obtained are regarded as fair approximations of the actual numbers of birds present in the areas.

None of the species studied occurred in large enough numbers for a sufficient period of time to allow a meaningful analysis of their individual migratory responses

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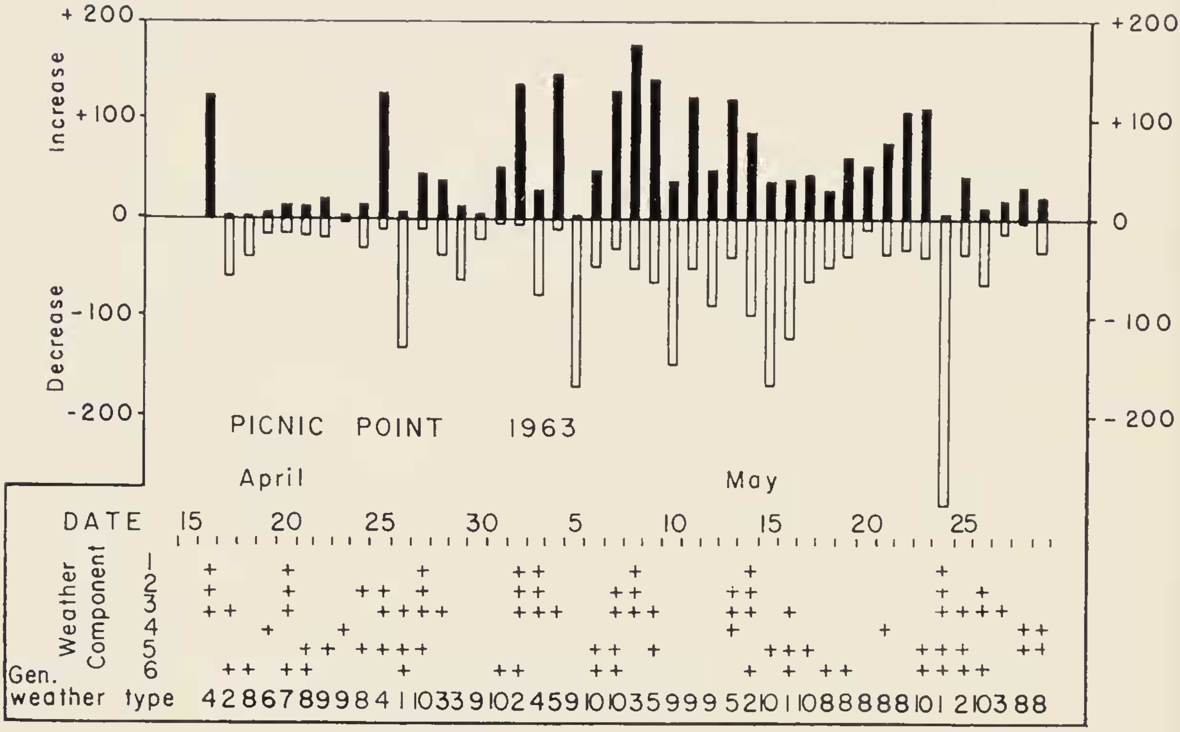

FIG. 1. Increases and decreases in numbers of migrants from previous day, 15 April to 29 May, 1963. Plus signs indicate presence of specific weather components: 1. temperature increase 10° F from previous evening; 2. temperature increase 5° F from previous evening; 3. calm or southerly winds (ESE-WSW); 4. rain in the evening; 5. winds less than 7 knots; 6. 30% cloud cover or less. The general weather situation for each night is given at bottom.

to weather. Therefore the daily counts for each of the species were pooled and only the total day-to-day changes considered. The day-to-day changes in numbers of migrants were found by summing the increases of all species that increased in numbers from the previous day and, independently, summing the decreases of all species that decreased from the previous day. For example, if 20 Myrtle Warblers (*Dendroica coronata*), 10 Palm Warblers (*Dendroica palmarum*) and 50 White-throated Sparrows (*Zonotrichia albicollis*) were observed on the first day, and 30 *D. coronata*, 40 *D. palmarum* and 15 *Z. albicollis* seen on the second day there would be an increase of 40 (10 for *D. coronata* plus 30 for *D. palmarum*) and a decrease of 35 (from 50 to 15 *Z. albicollis*). For every day there was thus both an increase and a decrease from the previous day, the increase being a measure of arrival and the decrease a measure of departure from the Madison area (Fig. 1, 2, and 3). (These changes inevitably include those resulting from counting errors, and local movements, as well as from actual migration. However, I feel migration was responsible for most of the large changes observed.) The day-to-day changes were calculated for each study area. In 1964 the Stevens Pond and Picnic Point data were lumped after total daily changes had been calculated for each. To obtain comparable figures based on daily change per twenty acres the daily change totals were multiplied by factors of 0.82 for 1964 and 3.0 for 1966.

The observed fluctuation in the numbers of grounded migrants was examined in relation to temperature, wind direction, wind strength, sky cover, precipitation, and

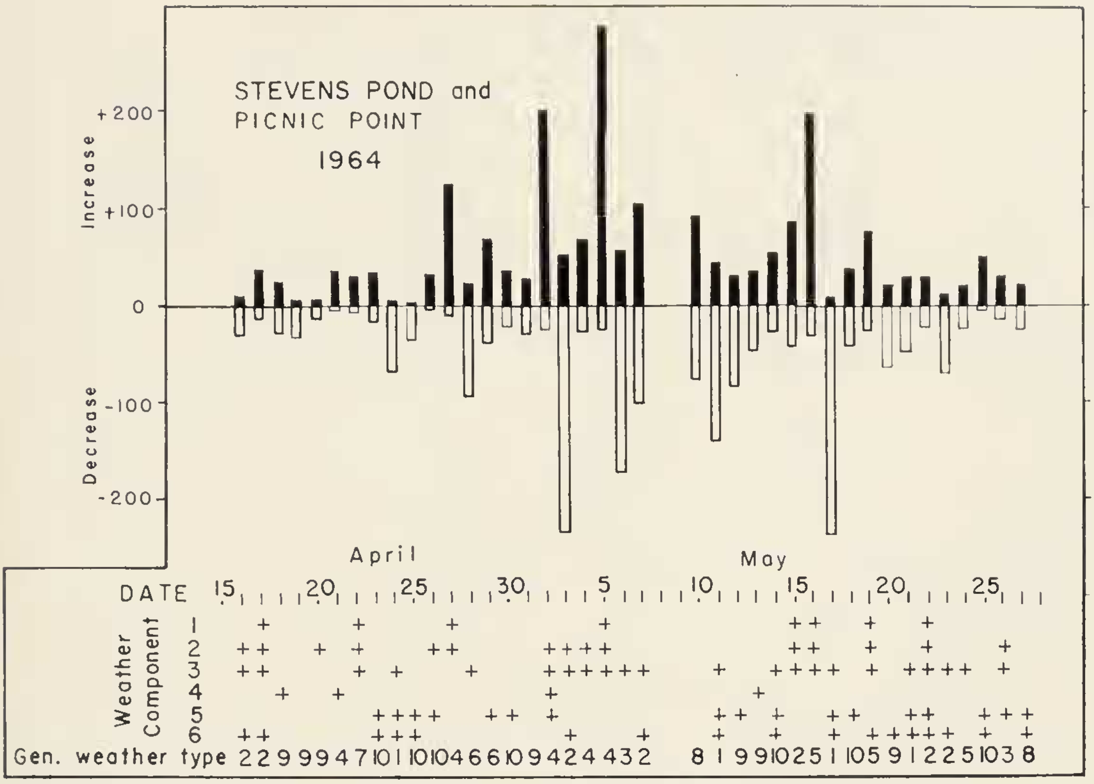

FIG. 2. Increases and decreases in numbers of migrants from previous day, 15 April to 27 May, 1964. Plus signs indicate presence of specific weather components: 1. temperature increase 10° F from previous evening; 2. temperature increase 5° from previous evening; 3. calm or southerly winds (ESE-WSW); 4. rain in the evening; 5. winds less than 7 knots; 6. 30% cloud cover or less. The general weather situation for each night is given at bottom.

general weather conditions. Meteorological information was obtained from the official U.S. Weather Bureau reports for Truax Field at Madison and the U.S. Weather Bureau's Daily Surface Maps. The method of correlating specific weather components with observed decreases in numbers of migrants follows that of Brooks (1965). All nights on which a given weather component to be tested for correlation occurred were considered plus nights for that component. All nights on which this condition did not exist were considered minus nights. For departures the average population decrease for plus nights was then compared with the average population decrease for minus nights by means of the Chi-square test. The same procedure was used for arrival data; however, the emphasis in this paper is placed on the relation of weather components to departures from the Madison area.

For this study, the hours near dusk (18:00 to 23:00 C.S.T.) were considered most critical for emigration. Observed decreases in migrant numbers were tested for correlation with the specific weather components which prevailed during this time period. The weather components which existed for each evening are shown in Figures 1, 2, and 3. For arrivals the time period from 22:00 to dawn is probably most important. Observed increases were tested for correlation with weather components occurring during the night. With the exception of night rainfall the occurrence of the weather components was the same as for departures (Fig. 1, 2, and 3).

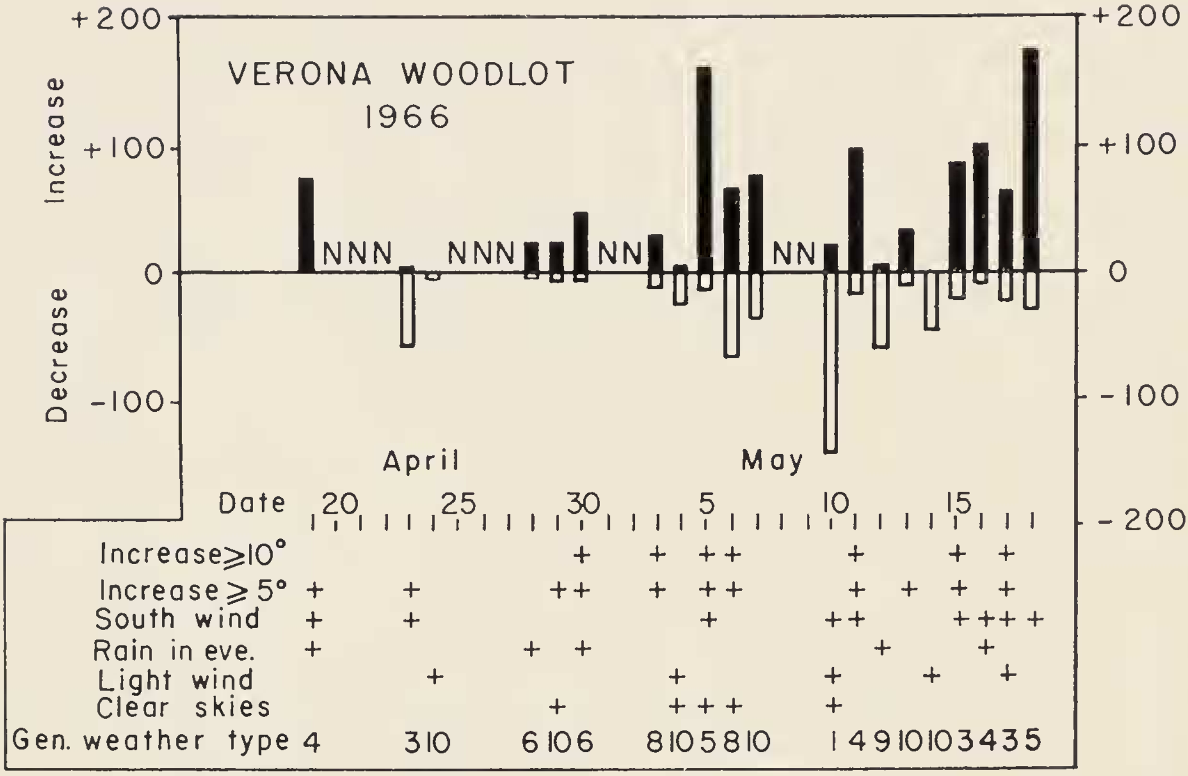

FIG. 3. Increases and decreases in numbers of migrants from previous day, 15 April to 21 May, 1966. The plus signs indicate presence of specific weather components. The general weather situation for each night is given at bottom.

SPECIFIC WEATHER COMPONENTS

Many studies have examined the relation of migration to the various weather components, and some controversy has arisen over the relative importance of each of a rather wide variety of weather components. Thus, Lack (1960*b*) regarded temperature as the single most important meterological factor in the inception of migration in spring, while wind direction (following wind) rather than temperature was considered important in summer and fall (Lack, 1963).

At Madison temperature increases of 10° F or more from the previous evening showed no correlation with observed decreases in numbers of birds (Table 1). Drury and Keith (1962) have suggested that in late spring temperature rises of 5° F were adequate stimuli. However, I found no correlation with temperature increases of 5° (Table 1). Arrivals at Madison were significantly correlated with both temperature increases of 5° F or more and temperature increases of 10° F or more (Table 2).

Devlin (1954) thought that south wind or calm at the critical time (hour just before nightfall) was most important in inducing migratory flight in spring, while Williams (1950) felt that wind direction was unimportant.

TABLE 1

CORRELATION OF DEPARTURES WITH SPECIFIC WEATHER COMPONENTS

Weather Components	Average Decrease Plus Nights	Average Decrease Minus Nights	Chi-square	Degree of Correlation
Temperature increase 10°F	–37.6	–50.0		no
from previous evening	n = 23	n = 81	2.2	correlation
Temperature increase 5°F	–31.8	–53.1		no
from previous evening	n = 39	n = 65	2.8	correlation
Southerly winds (ESE to WSW)	–56.9	–38.0		Positive correlation
or calm	n = 51	n = 53	3.8	$P \leq 0.05$
Rain in evening	–19.8	–52.2		Negative correlation
	n = 15	n = 89	15.9	$P \leq 0.01$
Light winds (less than 7 knots)	–55.9	–42.1		no
	n = 39	n = 65	2.2	correlation
Clear skies (30 per cent cloud	–63.1	–37.0		Positive correlation
cover or less)	n = 39	n = 65	7.5	$P \leq 0.01$

At Madison, there was a positive correlation with southerly winds (Table 1). Arrivals were strongly correlated to southerly winds (Table 2).

Lack (1960*b*) concluded that very little emigration occurred with rain or mist. Rainfall during the hours around dusk seemed to inhibit emigration from Madison (Table 1). Arrivals were correlated with night rainfall (Table 2).

Most researchers agree that strong winds, regardless of direction, inhibit migration and that migration is correlated with light winds. Lack (1960*a*) showed that radar studies of the spring emigration in Norfolk established statistically that more emigration occurred with light than strong winds. The data from the Madison study showed greater average decrease for evenings with winds less than 7 knots than for evenings with stronger winds, but the difference is not significant (Table 1).

Most researchers have concurred that migration is favored by clear to partly cloudy skies. Some migration also occurs on nights of complete overcast (Hassler et al., 1963; Drury and Nisbet, 1964; and others). More birds departed from the Madison area when there was less than 30 per cent cloud cover (Table 1). Arrivals showed no correlation with light winds or clear skies (Table 2).

GENERAL WEATHER PATTERNS

Lack (1960*b*) concluded that the volume of emigration is determined by particular weather factors and not by general weather situations. Later (1962), however, Lack found that the general weather situation significantly

TABLE 2

CORRELATION OF ARRIVALS WITH SPECIFIC WEATHER COMPONENTS

Weather Components	Average Increase Plus Nights	Average Increase Minus Nights	Chi-square	Degree of Correlation
Temperature increase 10°F	+88.6	+45.4		Positive correlation
from previous night	n=23	n=81	22.3	P ≤ 0.01
Temperature increase 5°F	+76.2	+42.1		Positive correlation
from previous night	n=39	n=65	11.2	P ≤ 0.01
Southerly winds (ESE to	+72.4	+38.1		Positive correlation
WSW) or calm	n=51	n=53	10.7	P ≤ 0.01
Rain during night	+73.3	+46.4		Positive correlation
	n=33	n=71	7.5	P ≤ 0.01
Light wind (less than 7 knots)	+44.2	+61.4		no
	n=39	n=65	2.8	correlation
Clear skies (30 per cent cloud	+43.9	+61.6		no
cover or less)	n=39	n=65	3.0	correlation

influenced migration. In any event, the reactions of birds to general weather situations can profitably be examined synoptically.

In temperate North America weather patterns drift eastward in a constant progression of high and low pressure systems each characterized by associated predictable patterns of wind, sky cover, and temperature variations. Thus, over the course of a spring season, various generalized synoptic patterns are repeated over southern Wisconsin in cycles. For purposes of analysis in this study ten stages of a typical weather cycle were recognized as depicted diagrammatically in Figure 4. All of the midnight weather patterns (as depicted on the Daily Weather Maps) for the migration seasons of 1963, 1964, and 1966 were classified and assigned to one of the ten possible stages (Figs. 1, 2, and 3). Because a few of the situations represented intermediates between two stages a subjective decision had to be made as to their assignment. All the population data for each of the days were then grouped with their respective weather types and the average population changes determined for each of the ten stages (Fig. 5).

Weather features and population changes during each of the ten selected stages of a weather cycle are as follows:

1. Conditions during stage one are characterized by calm to light southerly winds, and clear skies. Large decreases in numbers of birds were observed under these conditions (implying emigration). This type of weather occurred a total of eight times during the course of the three spring seasons, and on each occasion the decrease in number of birds far exceeded the increase (Fig. 5).

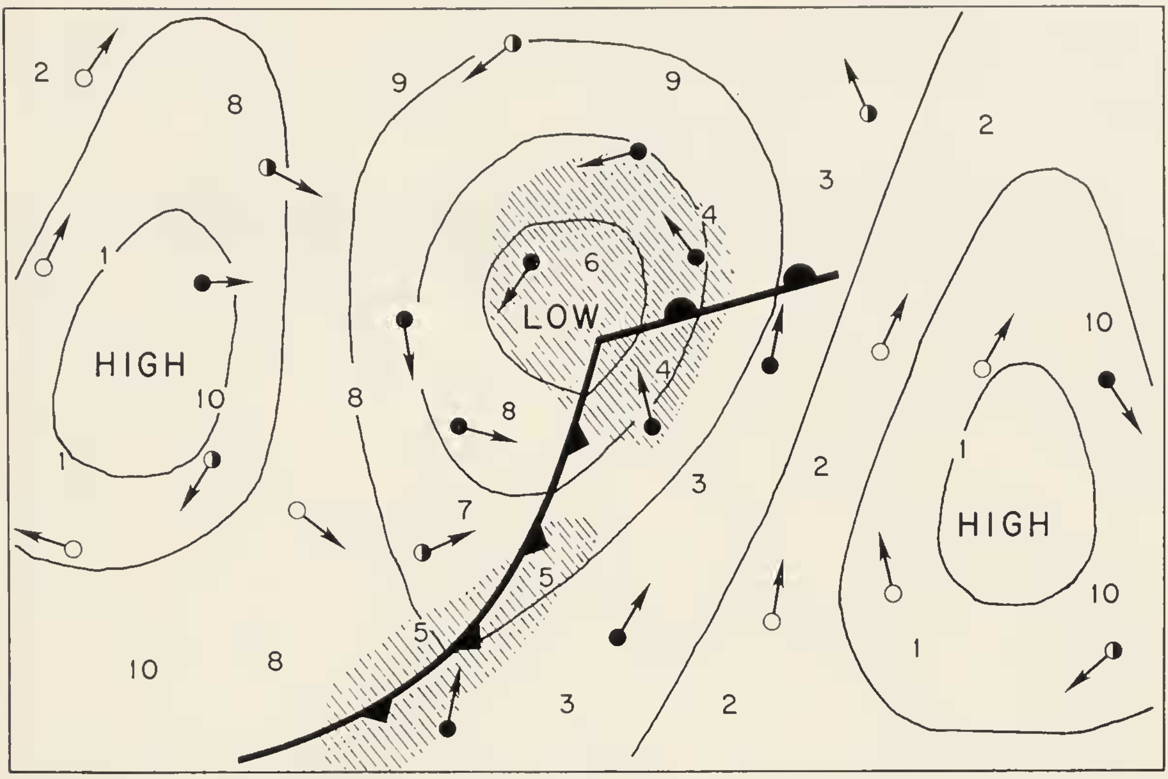

FIG. 4. Hypothetical map of a typical spring weather cycle with a high pressure system to the east (with clockwise winds) followed by a low pressure system (with counterclockwise winds and associated fronts and rain activity), followed by another high pressure system. These patterns drift eastward across North America. The numbers denote the ten zones or stages of a typical spring weather cycle as used in this study for correlation with migration. High levels of migration occurred in the region of northward airflow (stages 1–5); low levels in zones 6–10. Greatest departures occurred in stages 1 and 2, while greatest arrivals occurred in stages 4 and 5. [cold front symbol] Cold front; [warm front symbol] Warm front; Shaded area—Rain activity. Arrows indicate wind direction with circles on arrows indicating sky conditions.

2. Substantial decreases occurred under the conditions of clear skies and well developed northward air flow (parallel north-south trending isobars) characteristic of weather stage two where the center of a high has moved farther to the east than in stage one. Some increases were also noted for type 2 weather (Fig. 5).

3. Stage 3 has conditions similar to those of stage two except the skies are mostly overcast. Somewhat larger average increase was noted than for stage two (Fig. 5). It seems probable that overcast grounded some of these arriving migrants. Mueller and Berger (1966) reported that the mean weight of migrant Swainson's thrushes was lowest after clear nights (15 per cent cloud cover or less) and highest after overcast nights (85 per cent cloud cover) indicating that the latter were probably grounded sometime early in the night by heavy overcast before a long flight had depleted their fat reserves.

4. As the high pressure center moves farther east and a low pressure system approaches from the west stage four is characterized by southerly winds with rain occurring over southern Wisconsin during the night.

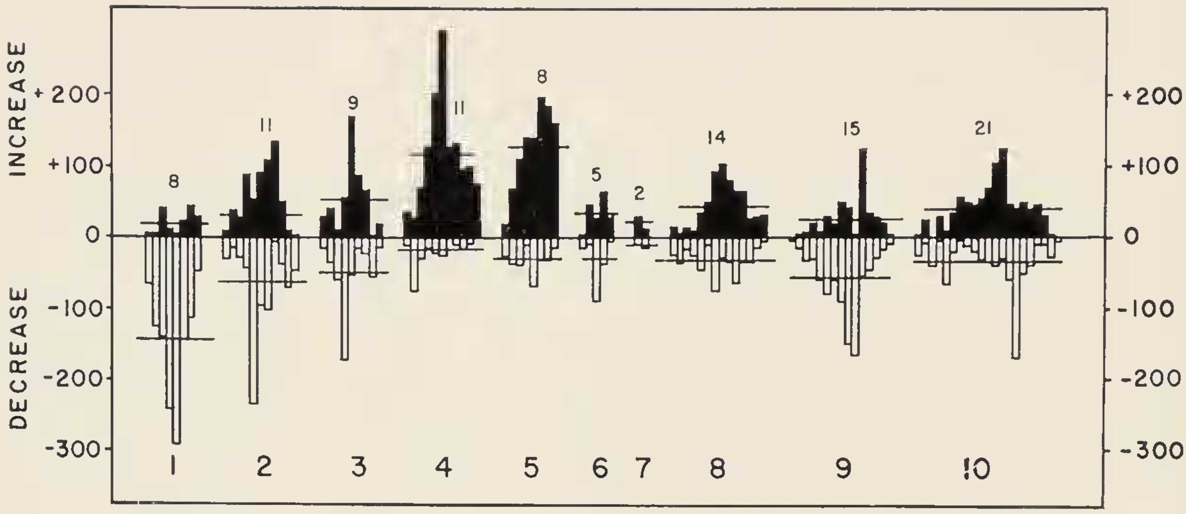

FIG. 5. Increases (shaded) and decreases (unshaded) in migrant numbers occurring under each of ten weather categories as shown in Figure 4. Each of the 104 nights is presented with average change for each weather category indicated by horizontal line. See text for description of ten weather categories.

5. Stage five shows essentially the same situation as that represented in stage four except that the rain is associated directly with a cold or stationary front, with characteristic drop in temperature and often a wind shift. Substantial increases were noted for both stage four and stage five weather conditions. Presumably this reflected large scale groundings of passing or "onrushing" migrants as they encountered moderate to heavy rains, thunderstorms, vertical and horizontal air turbulence, or shifts in wind direction. Bagg et al. (1950) referred to these massive groundings as "arrested waves." Lack (1960*b*), Dennis (1954), and others reported similar groundings associated with rain and fronts.

Significant decreases sometimes took place on the night following a night of frontal or precipitation grounding. These decreases can be explained by local dispersal during the day following such a grounding, as suggested by Mueller and Berger (1966). Alternatively, these decreases could have been due largely to emigration. This assumes the physiological "drive" to continue migration remained high following nights of interrupted flight, especially if these interruptions occurred early in the night before fat reserves were substantially reduced.

The first five weather stages fairly well represent the overall pattern typical of the zone of southerly winds occurring on the west side of a high pressure cell and in the warm sector of a low pressure system (Fig. 4). As Bagg et al. (1950) have suggested, it is in these zones of northward airflow that the majority of the birds migrate in the spring. At Madison the greatest daily turnover of migrants occurred under the conditions applying in stages one to five (Fig. 5).

6. The weather pattern associated with the center of a low (as represented by stage six) occurred on only five evenings. Little migration would be expected under such disturbed conditions. Nisbet (1957) has remarked: "The principal feature of the reactions of the birds to weather changes is a strong discrimination against migrating in active cyclonic weather." The changes in numbers noted at Madison with stage six weather were small (Fig. 5).

7. Stage seven shows the strong southwesterly winds that sometimes occur after the passage of a cold front. The key feature is the cooler southwesterly winds, with air of continental polar or arctic origin. Small numerical changes occurred with this weather situation, which occurred on only two nights. Usually westerly to northeasterly winds occur after the passage of a cold front.

8, 9. Stages eight and nine are characterized by northwesterly and northeasterly winds associated with the cold sector of a low and the eastern portion of a high.

10. Stage ten represents the situation on the east side of a high pressure cell characterized by light variable winds (usually northerly) and quite often, cloudy skies. Average increases were generally light (with a few exceptions) and were approximately balanced by decreases for eight, nine, and also for ten (Fig. 5).

In summary, the average turnover for weather patterns represented by stages six–ten was relatively low as compared with that for stages one–five (Fig. 5).

DISCUSSION AND CONCLUSION

The observations obtained in this study support those of other students of bird migration that the major portion of the spring migrants proceed northward in the flow of southerly winds that occurs in the region to the west of a high pressure system, and in the warm sector of a low pressure system. The weather conditions that apply at such times provide assistance to northward progress in the form of tail winds. While Lowery and Newman (1955) have clearly shown that the flight directions very often do not correspond exactly to the prevailing wind direction, flying into headwinds is not a common feature of long distance nocturnal migration. Mueller and Berger (1966) have presented further data in support of this and note that it would be inefficient for a bird to continue migration into an appreciable head wind.

The analyses made in this study show that a large portion of migrants seem to receive their cues for departure from the Madison area just before the development of north-south trending isobars and northward airflow. It is as though the rather neutral conditions of a high pressure center carry information on the sustained period of northward airflow that will generally follow. This is not to imply that the birds anticipate favorable migrating conditions (sustained following winds) before they occur but that natural selection has favored responses to weather cues which generally precede northward airflow. It seems unlikely that birds are able to respond to general weather as such, but quite probably they do respond to combinations of specific weather components that are characteristic of a general weather situation. For example, perhaps the birds are able to respond to the passage of a high pressure ridge by one or more of the following characteristic features: clear skies or winds shifting to southerly or calm. Devlin (1954) found that calm conditions were favorable for migration and that on each of nine calm spring nights "there was a 'breeze' from the south 100 feet above the ground." Decrease in the observed numbers of migrants at Madison showed positive correlation with clear skies, calm or southerly winds or winds shifting to southerly, weather components characteristic of the passage of a high pressure ridge.

There have been many diverse opinions on which individual weather components are important to migration. Analyzing migrational activity with specific weather components alone, generally fails to produce a clear pattern of overall migrant response to weather. The various weather components are not independent variables but are related to one another and to the general weather situation. The effects of specific weather components on migration should be examined in relation to the general weather situations rather than independently.

SUMMARY

1. During the springs of 1963, 1964, and 1966 the day-to-day changes in numbers of "stopover" migrants at several study areas near Madison, Wisconsin, were used as an index to the arrival and departure of spring migrants in south-central Wisconsin.

2. The daily changes in numbers of stopover migrants were statistically correlated with weather components by means of the Chi-square test. Decreases in numbers of migrants at Madison were found to be positively correlated with clear skies and calm or southerly winds. Temperature changes showed no correlation and rain was found to be unfavorable for the initiation of migratory flight. Arrivals were correlated with southerly winds, night rainfall and temperature increases of 10° F or more or 5° F or more from the previous evening.

3. Ten weather patterns representing successive stages of a typical spring weather cycle were chosen and each of the nights of the three spring migration seasons assigned to one of these stages. The average increase and decrease in number of migrants per night were then calculated for each stage. Significant migration occurred in the weather zone stages between a high pressure system on the east and a low pressure system on the west. Largest decreases were observed when the center of a high pressure system was located just east of Wisconsin. As a low pressure system approached and moved through Wisconsin from the west, large numbers of migrating birds were grounded by shower activity and frontal passage. Little evidence of migration was noted in the weather zones to the west or north of a low pressure center or in the east sector of a high pressure system.

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LITERATURE CITED

BAGG, A. M., W. W. H. GUNN, D. S. MILLER, J. T. NICHOLS, W. SMITH, AND F. P. WOLFARTH. 1950. Barometric pressure-patterns and spring bird migration. Wilson Bull., 62:5–19.

BENNETT, H. R. 1952. Fall migration of birds at Chicago. Wilson Bull., 64:197–220.

BROOKS, W. S. 1965. Effects of weather on autumn shorebird migration in east-central Illinois. Wilson Bull., 77:45–54.

DENNIS, J. V. 1954. Meteorological analysis of occurrence of grounded migrants at Smith Point, Texas, April 17, May 17, 1951. Wilson Bull., 66:102–111.

DEVLIN, J. M. 1954. Effects of weather on nocturnal migration as seen from one observation point at Philadelphia. Wilson Bull., 66:93–101.

DRURY, W. H., AND J. A. KEITH. 1962. Radar studies of songbird migration in coastal New England. Ibis, 104:449-489.

DRURY, W. H., JR., AND I. C. T. NISBET. 1964. Radar studies of orientation of songbird migrants in southern New England. Bird-Banding, 35:69–119.

HASSLER, S. S., R. R. GRABER, AND F. C. BELLROSE. 1963. Fall migration and weather, a radar study. Wilson Bull., 75:56–77.

LACK, D. 1960*a*. Migration across the North Sea studied by radar. Pt. 2. The spring departure, 1956–1959. Ibis, 102:26–57.

LACK, D. 1960*b*. The influence of weather on passerine migration. A review. Auk, 77:171–209.

LACK, D. 1962. Migration across the southern North Sea studied by radar. Pt. 3. Movement in June and July. Ibis, 104:74–85.

LACK, D. 1963. Migration across the southern North Sea studied by radar. Pt. 5. Movements in August, winter and spring, and conclusion. Ibis, 105:461–492.

LOWERY, G. H., JR., AND R. J. NEWMAN. 1955. Direct studies of nocturnal bird migration. *In* A. Wolfson (Ed.) Recent studies in avian biology. University of Illinois, Urbana.

MUELLER, H. C., AND D. BERGER. 1966. Analyses of weight and fat variations in transient Swainson's Thrushes. Bird-Banding, 37:83–112.

NISBET, I. C. T. 1957. Passerine migration in south Scandinavia in the autumn of 1954. Ibis, 99:228–268.

WILLIAMS, G. G. 1950. Weather and spring migration. Auk, 67:52–65.

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