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THE EFFECT OF SHORT-TERM WEATHER CONDITIONS ON THE MIGRATION OF WATERFOWL

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Final Report

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16. Abstract

The effect of weather conditions on the fall migration of seven duck species was studied in the Illinois and Mississippi River Valleys of Illinois, October 1-December 5, 1948-1968, and on observed flock arrival and departure dates. Arrivals were treated as if the ducks departed Fargo, N. Dak., the evening before they arrived, and departures were related to weather conditions at Peoria, Ill.

A stepwise multiple regression equation was used to evaluate the effect of weather elements on duck departures. Correlations were highest for mallards *(Anas platyrhynchos)* and canvasbacks *(Aythya valisineria)*. Since correlation of weather conditions with duck departures generally was low, endogenous (physiological) factors apparently affected departure time more than exogenous (environmental) ones. Temperature and pressure were the weather elements most frequently associated with duck departures.

Duck departures from both areas also were studied in relation to weather fronts and high- and low-pressure centers, as located from synoptic charts. Most departures deemed related to fronts occurred when the fronts were so distant from departure areas that front-associated conditions had minimal effect. The frequency of passage with various types of fronts was similar to the frequency of these fronts when no duck migration was detected. Thus, to predict waterfowl passage in the Midwest based on weather information available to flight controllers would be difficult.

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INTRODUCTION

One of the many problems inherent in determining the difference of weather effects on different species is the difficulty of identifying species in large migrating flocks. Techniques currently employed, such as observing birds passing the face of the moon and radar surveillance of birds in the air space, generally do not provide knowledge on the particular species involved.

The present study on waterfowl migration in relation to weather factors attempts to overcome the deficiency of species analysis by employing two sets of migration data--periodic waterfowl censuses by species, and dates of the occurrence of waterfowl arrivals and departures. The periodic waterfowl censuses provide information on the magnitude and species composition of waterfowl passages; the arrival and departure dates provide information on the exact dates of specific movements.

The primary objective of this study was to evaluate variations in the magnitude of the fall migration for each important species of game duck with respect to prevailing weather conditions at the time of their departures. The region of evaluation of weather influence was the northern half of the Mississippi River Migration Corridor (Bellrose 1968:8,11).

PROCEDURES

Population Data

Waterfowl censuses for a 21-year period (1948-1968) were conducted at approximately weekly intervals during the fall in the Illinois and Mississippi River Valleys. A light aircraft was used to survey the lakes and marshes between Spring Valley and Grafton, Illinois, in the Illinois River Valley and between Alton and Moline, Ill., in the Mississippi River Valley. The surveys covered a variety of waterfowl habitats embracing about 50,000 acres in the Illinois Valley and about 150,000 acres in the Mississippi Valley, together comprising about 65 percent of the waterfowl habitat in Illinois.

The census data were employed to determine the chronology of migration for each species. I believe that the sizeable coverage of a variety of waterfowl habitats provided a fairly accurate estimate of the species composition of waterfowl migrating through this region of the nation.

Because departures were often marked by arrivals of still larger numbers of the same species, it was necessary to analyze the census data in considerable detail. Usually when a flight of ducks arrives in Illinois from the north-northwest there is a departure of local ducks on the same night or on the following night. However, I have noticed on numerous occasions that the new influx by a particular species is not distributed

evenly in specific local areas, nor is the accompanying departure. For example, a lake that had 30,000 mallards may contain only 10,000 after a passage, whereas a lake formerly with 5,000 mallards may contain 60,000. Intensive banding of ducks in Illinois (Bellrose and Crompton 1970) shows that rarely is there a large relocation of ducks that have reached their home lake. Usually the change in the numbers of ducks on a given area is the result of either migrational ingress or egress and not a combination.

In order to estimate with maximum accuracy the magnitude of the ingress and egress of a species in the censused area, comparisons of changes in populations between censuses were made on the basis of each individual unit censused. A unit in the Illinois Valley consisted of either a single lake, 1,000 to 4,000 acres in extent, or several contiguous small lakes and marshes. In the Mississippi Valley, a unit consisted of a 10- to 30-mile section of the Mississippi River and adjacent water areas. Comparisons in periodic population changes were made for each of 44 units in the Illinois River Valley and for each of 26 units in the Mississippi River Valley. Total arrivals and departures then were determined by summing the results for all units.

Migration Dates

The specific dates on which arrivals and departures of waterfowl occurred were determined in several ways. Birds in passage were frequently observed as they entered or departed the Illinois and Mississippi River Valleys. Also, regular observations were made on the abundance of waterfowl on particular lakes and marshes where large concentrations occurred. Besides personal observations, close contact was maintained with numerous experienced observers who were daily in the field. These cooperating observers consisted of refuge personnel of the U.S. Bureau of Sport Fisheries and Wildlife, the caretakers of duck clubs, veteran duck guides, and State game biologists.

A comparison of radar surveillance of waterfowl migration at Havana, Illinois, with visual observations (Bellrose 1964) showed close agreement in determining dates of passage. A few passages of waterfowl were missed visually, and, likewise, a few passages went undetected by radar. The undetected passages appeared to be of small size.

I am confident that 90 percent of the waterfowl flights that resulted in a population change greater than 10 percent were detected. During 1948-1968, arriving flights were detected on 43 percent of October and November days, and departures were detected on 36 percent of those days. Usually a single migratory pulse extended for 2 days, occasionally 3 days, and rarely 4 days. Occasionally two distinct migratory pulses were noted between weekly waterfowl censuses.

Because ingress and egress of waterfowl in the censused area generally occurred on more than one date between weekly censuses, it was necessary to prorate the magnitude of the weekly change for each date during the week in

which the flights occurred. A percentage of the weekly change in abundance was assigned to each interim date. This percentage was based either upon daily records, which suggested the magnitude of the observed flight, or on the daily change noted in the abundance of local duck populations. At times, the percentage assigned to each date was little more than an educated guess. The magnitude of the measured change from week to week was necessarily greater than the estimated change for a given day. Therefore, the errors made in estimating the magnitude of daily changes should be relatively small compared to the weekly change. However, this estimation of the daily population change between weekly censuses must be considered as introducing errors of small magnitude, and reducing the correlation of waterfowl flights with weather data for the date.

Arrivals of ducks in the Illinois and Mississippi River Valleys of Illinois were treated as if they had departed from Fargo, North Dakota. Fargo was selected because it is on the principal migration corridor followed by ducks entering the census area (Bellrose 1968). Furthermore, it is about the distance migrating ducks would be most likely to cover in a single flight. Ducks depart in migration at the greatest rate between 1800 and 2200 c.s.t. (Bellrose 1964 and unpublished) and arrive at their destination between 0500 and 0900. Thus, in flight for probably between 6 and 12 hours at 60 miles per hour, migrating ducks would travel from 360 to 720 miles. Fargo is 470 miles from the closest point on our census area and 650 miles from the most distant point. A passage of ducks arriving in Illinois during the forenoon of one day was treated as leaving the Fargo area at 1900 the previous day. Departures of ducks from the Illinois and Mississippi River Valleys were treated as departures at 1900 from the Peoria area, near the center of our waterfowl census area.

Weather Data

Weather stations located at Fargo and Peoria were selected for analysis of weather conditions relative to the fall waterfowl migration. Weather data from Fargo were used for analysis of weather factors influencing the arrival of ducks in the Illinois and Mississippi River Valleys, and data from Peoria for departures. The weather stations at both Fargo and Peoria recorded observations of weather on an hourly basis from 1948 to January 1965 and then on a 3-hour basis from January 1965 to date. Because these records could be obtained on computer tape only for the years 1948-1968, the analysis was restricted to this 21-year period even though waterfowl data were avilable for additional years. Computer tapes of weather data were obtained from the National Climatic Center, Asheville, North Carolina.

All the basic weather elements recorded by U.S. Weather Service stations were used in this analysis, including certain weather items 1 and 2 days prior to the estimated departure of waterfowl. The 33 weather parameters analyzed in relation to duck passages in and out of the census area for each day during the census period are as follows:

W 1. Ceiling height (feet) at 1900.
W 2. Visibility (miles) at 1900.
W 3. Light rain at 1900 (yes or no).
W 4. Moderate rain at 1900 (yes or no).
W 5. Heavy rain at 1900 (yes or no).
W 6. Light snow at 1900 (yes or no).
W 7. Moderate snow at 1900 (yes or no).
W 8. Heavy snow at 1900 (yes or no).
W 9. Dew point (°F) at 1900.
W10. Dew point change during the 6 hours previous to 1900.
W11. Barometric pressure (millibars) at 1900.
W12. Barometric pressure change during the 6 hours previous to 1900.
W13. Barometric pressure change during the 24 hours previous to 1900.
W14. Barometric pressure change during the 48 hours previous to 1900.
W15. Temperature (°F) at 1900.
W16. Temperature change during the 6 hours previous to 1900.
W17. Temperature change during the 24 hours previous to 1900.
W18. Temperature change during the 48 hours previous to 1900.
W19. Wind direction relative to assumed direction of flight (145°) at 1900.
W20. Wind speed (knots) at 1900.
W21. Tail wind speed at 1900.
W22. Change in tail wind speed during the 24 hours previous to 1900.
W23. Cross wind speed at 1900.
W24. Change in cross wind speed during the 24 hours previous to 1900.
W25. Sky cover (0 or 1) at 1900.
W26. Barometric pressure at 1900 on the previous day.
W27. Temperature at 1900 on the previous day.
W28. Tail wind speed at 1900 on the previous day.
W29. Cross wind speed at 1900 on the previous day.
W30. Barometric pressure at 1900, 2 days earlier.
W31. Temperature at 1900, 2 days earlier.
W32. Tail wind speed at 1900, 2 days earlier.
W33. Cross wind speed at 1900, 2 days earlier.

Data Preparation and Processing

The seasonal numbers of ducks of each species arriving and departing each year were normalized to provide yearly data of equal rank. Normalization was achieved by converting the number of ducks departing each day to a percentage of the total departures for the fall of that year (multiplied by 100) to make all the departures in 1 year comparable to all the departures in any other year. Arrivals in Illinois (departures from Fargo) were treated in the same way.

For each date of the migration season, the average number of normalized departures was computed for the 21-year period. This average was smoothed by using an 11-day centered moving average.

In order to take account of the seasonal variation in numbers of ducks normally arriving and departing, two functions were employed to describe variations from average numbers:

$F = N-AV$ and

$F = N/AV$,

where N = the number of departures for a given date in any year, and

AV = the average number of departures for the same date over the 21-year period.

Preliminary analyses showed that multiple correlation with weather factors was consistently greater for the function $F = N-AV$ than for $F = N/AV$. Results are therefore reported only for $F = N-AV$. This function was regressed on the listed weather parameters for each species of waterfowl, for arrivals and departures, and for each of three groupings:

(1) All cases.

(2) Cases where $N>AV$ ($F>0$).

(3) Cases where $N<AV$ ($F<0$).

Comparison of results from the above three groupings showed that correlations were much lower when all cases were included, than when $N>AV$ and $N<AV$ cases were treated separately. This finding suggests that there is a threshold effect rather than a linear relation over the whole range of migration magnitudes. When only "small" ($N<AV$) flights or "large" ($N>AV$) flights are considered, it is assumed that weather factors would be linearly related to the function $F = N-AV$, within the "small" or "large" category only. The remainder of the discussion is therefore based on separate statistical treatment of each species of duck, for departure from both Fargo and Peoria, and for each category, $N>AV$ and $N<AV$.

Evaluation of the influence of 33 weather variables on the relative magnitude of migration ($F = N-AV$) for each of seven species of ducks was made by a stepwise linear multiple regression program. This program was developed by the SOUPAC group at the Digital Computer Laboratory, the University of Illinois.

The stepwise program included calculation of $\underline{t}$ values for each coefficient. Because sample sizes varied between a low of 202 and a high of 1,164, a $\underline{t}$ value of 1.96 or higher was significant at the 0.05 level. Computer analyses were examined, and the final regression equation was taken to be the last step in which all coefficients had a $\underline{t}$ value greater than 1.96. The coefficient of determination (R^2), the unstandardized regression coefficients, the Y intercept, and the residual estimate of error (standard error of estimate) were determined at this step.

The coefficient of determination gives the proportion of the variance of the dependent variable about its mean, which has been "explained" by the estimating equation.

Migration data for seven species of ducks were used in analysis, because they were most numerous during the entire period of observation. Although the blue-winged teal *(Anas discors)* is an abundant species, it started migrating through Illinois prior to the start of our aerial surveys of waterfowl populations; because data for it were incomplete, it was omitted from this analysis. The seven species of ducks for which the population data were deemed valid, and, therefore, used in this study are: (1) mallard; (2) pintail *(Anas acuta)*; (3) green-winged teal *(Anas crecca)*; (4) wigeon *(Anas americana)*; (5) lesser scaup *(Aythya affinis)*; (6) ring-necked duck *(Aythya collaris)*; and (7) canvasback.

Weather Map Analysis

In addition to the multiple regression analysis of duck migration data in relation to coded weather variables, a study was made of the weather systems shown on daily weather maps in relation to waterfowl migration. The various types of fronts or the absence of fronts were related to the departures of ducks from the Fargo and the Peoria areas.

Daily weather maps issued by the Environmental Data Service, National Oceanic and Atmospheric Administration, for 0700 e.s.t. each day were examined for fronts located in positions (relative to Fargo and Peoria) that might have influenced migration of waterfowl. Judgments were necessarily subjective, and were based on locations and estimated movements, for both preceding and following days, that would indicate that weather phenomena associated with the front would have occurred in the departure area during the day of departure. The position of the front was specified by the direction and distance from Fargo or Peoria to the nearest point on the front as shown on the 0700 map. A position southeast of Fargo, for example, would indicate a cold front had passed Fargo from the northwest. A warm front position south of Fargo would indicate that a northward-moving front was approaching. Similar considerations apply to the various types of fronts in various positions.

The locations of the high- and low-pressure centers associated with the various fronts were recorded by longitude and latitude, also determined for the weather-map time of 0700.

RESULTS

Ducks were observed arriving in the study zone on an average of 27.9 (42.3 percent) of the 66 days each year (October 1-December 5), 1948-1968 (Table 1). In any one year, ducks were detected arriving from a low of

Table 1. The number of days (October 1-December 5) from 1948 through 1968 that ducks were observed arriving and departing the Illinois and Mississippi River Valleys, Illinois

Year	Arrivals		Departures	
	Number	Percent	Number	Percent
1948	22	33.3	22	33.3
1949	12	18.2	12	18.2
1950	17	25.8	14	21.2
1951	11	16.7	10	15.2
1952	18	27.3	18	27.3
1953	23	34.8	23	34.8
1954	23	34.8	22	33.3
1955	24	36.4	17	25.8
1956	26	39.4	23	34.8
1957	32	48.5	24	36.4
1958	34	51.5	26	39.4
1959	31	47.0	22	33.3
1960	35	53.0	28	42.4
1961	27	40.9	25	37.9
1962	32	48.5	31	47.0
1963	36	54.5	33	50.0
1964	24	36.4	23	34.8
1965	43	65.2	35	53.0
1966	38	57.6	30	45.5
1967	39	59.1	28	42.4
1968	39	59.1	27	40.9
Total	586		493	
Average	27.9	42.3	23.5	35.6

16.7 percent (1951) to a high of 65.2 percent (1965) of the days in the study period.

Likewise, ducks departed the study zone an average of 23.5 (36.6 percent) of the 66 days. The lowest number of departures occurred in 1951, with flights on 15.2 percent of the days, whereas the highest number was in 1965 when they occurred on 53 percent of the days.

The fact that duck flights arrived and departed on over one-third of the nights, suggests that a narrowly specific set of weather conditions is not required for migration flights. Migration is possible under a wide spectrum of weather patterns.

Tables 2 and 3 summarize the effects of the combined weather factors on departures of seven species of ducks, as determined by the multiple regression calculations. Statistics are shown separately for the two categories, N>AV and N<AV.

Fargo Departures

Among the larger-than-average departures from the Fargo area, weather variables appeared to exert the greatest influences on mallards and canvasbacks, with lesser influences on pintails, wigeons, ring-necked ducks, green-winged teals, and lesser scaups, in that order (Table 2).

The smaller-than-average departures showed more influence from weather variables than did the larger-than-average departures for all species except the lesser scaup and ring-necked duck. The smaller-than-average departures of mallards, wigeons, canvasbacks, green-winged teals, and pintails had moderately high correlations with weather conditions (R^2 between 0.281 and 0.472). The lesser scaup and ring-necked ducks had very low R^2 values, less than 0.055 (Table 2).

Peoria Departures

Smaller-than-average departures of all species of ducks from the Peoria area were also influenced more by weather variables than were the larger-than-average departures (Table 3). The departure of larger-than-average numbers was more strongly correlated with weather factors for mallards, lesser scaups, canvasbacks, and ring-necked ducks (R^2 between 0 135 and 0.194); low correlations occurred for the wigeon, green-winged teal, and pintail (R^2 less than 0 055).

Correlations with weather elements were high for smaller-than-average departures of mallards, canvasbacks, lesser scaups, and ring-necked ducks; they were low for wigeons, pintails, and green-winged teals (Table 3).

The data in Tables 2 and 3 suggest the following general deductions: (1) factors other than the weather factors considered were responsible for

Table 2. The effect of short-term weather conditions on the magnitude of daily departures among seven species of ducks, 1948-1968, at Fargo, North Dakota, calculated from stepwise multiple linear regression

	N > A V#			N < A V#		
Species	Multiple correlation coefficient (R)*	Coefficient of determination (R^2)*	Residual estimate of error	Multiple correlation coefficient (R)*	Coefficient of determination (R^2)*	Residual estimate of error
Mallard	0.493	0.243	469.65	0.688	0.472	90.13
Pintail	0.286	0.082	657.40	0.530	0.281	73.52
Green-winged Teal	0.247	0.061	502.79	0.614	0.377	65.11
Wigeon	0.270	0.073	733.40	0.653	0.427	85.75
Lesser Scaup	0.210	0.044	756.16	0.210	0.044	756.16
Ring-necked Duck	0.250	0.063	693.55	0.230	0.054	107.46
Canvasback	0.385	0.148	1,489.61	0.629	0.396	126.96

#N>AV = larger-than-average departures; N<AV = smaller-than-average departures

*Regression coefficients significant ($P<0.05$)

Table 3. The effect of short-term weather conditions on the magnitude of daily departures among seven species of ducks, 1948-1968, at Peoria, Illinois, calculated from stepwise multiple linear regression

Species	N > A V#			N < A V#		
	Multiple correlation coefficient (R)*	Coefficient of determination (R^2)*	Residual estimate of error	Multiple correlation coefficient (R)*	Coefficient of determination (R^2)*	Residual estimate of error
Mallard	0.441	0.194	1,785.63	0.724	0.524	277.72
Pintail	0.198	0.039	760.82	0.267	0.071	70.29
Green-winged Teal	0.204	0.042	482.51	0.223	0.050	65.45
Wigeon	0.232	0.054	784.06	0.302	0.091	88.90
Lesser Scaup	0.394	0.155	873.14	0.596	0.355	106.95
Ring-necked Duck	0.368	0.135	880.10	0.592	0.350	101.35
Canvasback	0.387	0.150	4,017.50	0.654	0.428	392.14

#N>AV = larger-than-average departures; N<AV = smaller-than-average departures

*Regression coefficients significant ($P<0.05$)

initiating most departures of ducks from both the Fargo and Peoria areas; (2) weather variables exhibited the greatest influence on smaller-than-average departures and the least influence on larger-than-average departures; (3) weather variables explained the departure of some species more than other species; and (4) differences between the Fargo and Peoria areas in the correlation of weather factors with duck departures were generally slight but were marked for the lesser scaup and ring-necked duck.

An in-depth examination of each of these general deductions follows.

Influence of Weather Elements

Most duck species migrate through Illinois over a period of 8 to 10 weeks. Some species migrate early during the fall, some late, and some in between. Because of the prolonged migration period, each species encounters many combinations of weather elements during its migration period. The regularity of migration and its relative continuity suggest that ducks can and do migrate under many weather patterns, some of which may appear to be the reverse of others. The use of regression analysis to evaluate each weather element with respect to its effect on migration can be expected to identify what specific combination of the weather factors under consideration appears to encourage or to discourage migratory movements. It cannot predict a fixed weather pattern or patterns which must appear before migration can occur. Examination of each weather element that is significant in the multiple regression will nevertheless enable us to make at least some broad generalizations as to the types of weather patterns that produce the specific conditions found to be significant.

Tables 4-17 are arranged to show the relative importance of each weather element found to be significant in the particular case considered. Weather factors are listed in the order in which they enter the stepwise regression calculation; this order indicates qualitatively the relative importance of the various factors. Quantitative statements as to the importance of a weather factor cannot be made, since almost all the weather variables are correlated with each other. The quantitative value of adding a variable is shown in these tables by the "Increase in R^2" column. The increase in R^2 measures the amount by which the use of k + 1 variables is better than the use of only k variables, but it does not measure the value of the last variable added per se.

Mallard.--Low, falling temperatures and low pressure on the previous day were the weather elements most important for larger-than-average mallard departures at Fargo (Table 4). These conditions suggest that a cold front had passed the departure area some 24-28 hours previously.

The more numerous smaller-than-average departures of mallards from the Fargo area were correlated with rising temperatures and high pressure (Table 4). These conditions, along with favorable tail winds, indicate mild, fair weather giving good flying conditions.

Table 4. Relative importance of weather elements affecting the departure of mallards from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	31	temp. - 48 hrs.	0.208	-17.82	1.62
2	18	temp. change, 48 hrs.	0.024	-7.56	2.34
3	26	pressure - 24 hrs.	0.011	-2.33	0.97
		Intercept		7,877.19	
		N<AV:			
1	31	temp. - 48 hrs.	0.396	5.56	0.19
2	18	temp. change, 48 hrs.	0.037	3.73	0.36
3	11	pressure, 1900	0.011	0.64	0.13
4	32	tail wind speed - 48 hrs.	0.007	1.12	0.28
5	21	tail wind speed, 1900	0.007	1.04	0.33
6	16	temp. change - 6 hrs.	0.006	2.94	0.73
7	17	temp. change - 24 hrs.	0.005	-1.52	0.47
8	20	wind speed, 1900	0.003	1.31	0.51
		Intercept		2,261.21	

*Regression coefficient for the indicated variable at the final step

Table 5. Relative importance of weather elements affecting the departure of mallards from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		[illegible]			
1	[illegible]	[illegible] 1900	0.123	-31.07	11.56
2	[illegible]	[illegible] snow [illegible]	0.029	1,902.65	647.58
3	[illegible]	[illegible]	0.032	-31.58	11.27
[illegible]	[illegible]	[illegible] speed [illegible]	0.014	-44.36	13.83
		Intercept		3,804.03	
		[illegible]			
1	[illegible]	[illegible]	0.389	9.40	1.34
2	[illegible]	[illegible]	0.063	12.24	1.40
3	[illegible]	[illegible] and speed [illegible]	0.030	8.94	1.36
4	6	[illegible] 1900	0.015	-380.91	75.31
5	2	[illegible] 1900	0.005	1.12	0.25
6	3	[illegible] speed. [illegible]	0.007	-5.52	1.71
[illegible]	[illegible]	[illegible] - 45 hrs.	0.004	1.66	0.50
[illegible]	[illegible]	[illegible] and speed - [illegible]	0.003	5.18	1.53
[illegible]	[illegible]	[illegible]	0.004	-4.13	1.58
[illegible]	[illegible]	[illegible]	0.003	50.26	20.14
10	[illegible]	[illegible]	0.002	654.63	288.06
		Intercept		-6,388.25	

*Regression coefficient for the indicated variable at the final step

Table 6. Relative importance of weather elements affecting the departure of pintails from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N AV:			
1	27	temp. - 24 hrs.	0.035	8.96	2.57
2	11	pressure, 1900	0.024	4.58	1.55
3	5	heavy rain, 1900	0.014	567.42	274.16
4	33	cross wind - 24 hrs.	0.009	-9.25	5.72
		Intercept		-13,680.41	
		N<AV:			
1	15	temp., 1900	0.257	-2.19	0.22
2	11	pressure, 1900	0.013	-0.38	0.10
3	31	temp. - 48 hrs.	0.008	-0.70	0.22
4	4	mod. rain, 1900	0.003	-26.61	13.19
		Intercept		1,117.96	

*Regression coefficient for the indicated variable at the final step

Table 7. Relative importance of weather elements affecting the departure of pintails from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	32	tail wind speed - 48 hrs.	0.019	-15.23	6.01
2	7	mod. snow, 1900	0.020	838.22	344.49
		Intercept		479.46	
		N<AV:			
1	9	dew point, 1900	0.023	1.24	0.16
2	21	tail wind speed, 1900	0.012	1.05	0.35
3	16	temp. change - 6 hrs.	0.017	3.09	0.57
4	17	temp. change - 24 hrs.	0.013	-1.24	0.32
5	2	visibility in miles	0.006	0.14	5.44
6	32	tail wind speed - 48 hrs.	0.005	0.82	0.33
		Intercept		-184.26	

*Regression coefficient for the indicated variable at the final step

Table 8. Relative importance of weather elements affecting the departure of green-winged teal from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	27	temp. - 24 hrs.	0.046	9.20	2.13
2	32	tail wind speed - 48 hrs.	0.015	6.31	2.82
		Intercept		-7.06	
		N<AV:			
1	15	temp., 1900	0.320	-2.64	0.32
2	11	pressure, 1900	0.026	-0.34	9.74
3	31	temp. - 48 hrs.	0.015	-1.37	0.24
4	30	pressure - 48 hrs.	0.006	-0.31	9.98
5	9	dew point, 1900	0.004	1.10	0.32
6	4	mod. rain, 1900	0.003	-27.54	12.40
7	5	heavy rain, 1900	0.003	-36.77	17.25
		Intercept		1,901.46	

*Regression coefficient for the indicated variable at the final step

Table 9. Relative importance of weather elements affecting the departure of green-winged teal from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	6	light snow, 1900	0.027	768.93	282.33
2	16	temp. change - 6 hrs.	0.015	-13.62	6.06
		Intercept		347.57	
		N<AV:			
1	16	temp. change - 6 hrs.	0.015	2.51	0.52
2	26	pressure - 24 hrs.	0.015	-0.36	0.10
3	6	light snow, 1900	0.012	52.88	14.90
4	21	tail wind speed, 1900	0.007	0.83	0.31
		Intercept		936.13	

*Regression coefficient for the indicated variable at the final step

Table 10. Relative importance of weather elements affecting the departure of wigeon from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	1	ceiling height, 1900	0.039	0.26	0.09
2	31	temp. - 48 hrs.	0.019	8.93	3.22
3	33	cross wind speed - 48 hrs.	0.015	-14.91	7.11
		Intercept		-64.65	
		N<AV:			
1	15	temp., 1900	0.364	-6.12	0.36
2	18	temp. change - 48 hrs.	0.034	1.32	0.31
3	11	pressure, 1900	0.011	-0.41	0.12
4	9	dew point, 1 900	0.007	1.74	0.42
5	32	tail wind speed - 24 hrs.	0.003	-0.79	0.25
6	17	temp. change - 24 hrs.	0.005	1.16	0.38
7	1	ceiling height, 1900	0.003	1.41	59.94
		Intercept		1,273.36	

*Regression coefficient for the indicated variable at the final step

Table 11. Relative importance of weather elements affecting the departure of wigeon from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	27	temp. - 24 hrs.	0.030	9.63	3.44
2	13	pressure change - 24 hrs.	0.024	6.04	2.29
		Intercept		-64.40	
		N<AV:			
1	15	temp., 1900	0.046	-3.12	0.41
2	9	dew point, 1900	0.025	2.07	0.42
3	16	temp. change - 6 hrs.	0.010	2.77	0.69
4	26	pressure - 24 hrs.	0.006	-0.38	0.13
5	25	sky cover, 1900	0.004	-15.03	6.22
		Intercept		1,091.03	

*Regression coefficient for the indicated variable at the final step

Table 12. Relative importance of weather elements affecting the departure of lesser scaup from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	7	mod. snow, 1900	0.026	1,724.89	762.51
2	13	pressure change - 24 hrs.	0.018	3.73	1.75
		Intercept		568.39	
		N<AV:			
1	26	pressure - 24 hrs.	0.015	-0.66	0.15
2	16	temp. change - 6 hrs.	0.014	4.15	0.85
3	25	sky cover, 1900	0.005	-19.57	7.20
4	21	tail wind speed, 1900	0.007	0.86	0.36
		Intercept		1,809.08	

*Regression coefficient for the indicated variable at the final step

Table 13. Relative importance of weather elements affecting the departure of lesser scaup from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	9	dew point, 1900	0.056	-21.76	5.28
2	28	tail wind speed - 24 hrs.	0.057	-30.24	8.53
3	24	change cross wind speed-24 hrs.	0.024	20.43	8.36
4	25	sky cover, 1900	0.018	-271.57	132.33
		Intercept		1,624.57	
		N<AV:			
1	31	temp. - 48 hrs.	0.263	4.41	0.64
2	32	tail wind speed - 48 hrs.	0.024	2.41	0.50
3	27	temp. - 24 hrs.	0.023	1.45	0.59
4	2	visibility miles, 1900	0.009	0.47	0.09
5	12	pressure change - 6 hrs.	0.008	-2.26	0.52
6	21	tail wind speed, 1900	0.010	2.88	0.63
7	18	temp. change - 6 hrs.	0.006	1.80	0.52
8	33	cross wind speed - 48 hrs.	0.005	-1.94	0.62
9	6	light snow, 1900	0.004	73.41	27.12
10	4	mod. rain, 1900	0.003	34.04	14.81
		Intercept		-507.38	

*Regression coefficient for the indicated variable at the final step

Table 14. Relative importance of weather elements affecting the departure of ring-necked ducks from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	2	visibility in miles	0.039	-4.91	1.32
2	16	temp. change - 6 hrs.	0.023	-26.94	10.61
		Intercept		1,138.39	
		N<AV:			
1	16	temp. change - 6 hrs.	0.012	4.79	0.80
2	26	pressure, 1900 - 24 hrs.	0.017	-0.50	0.16
3	25	sky cover, 1900	0.007	-18.06	6.85
4	21	tail wind speed, 1900	0.007	1.04	0.34
5	27	temp. - 24 hrs.	0.006	0.62	0.20
6	32	tail wind speed - 24 hrs.	0.005	0.76	0.31
		Intercept		1,327.26	

*Regression coefficient for the indicated variable at the final step

Table 15. Relative importance of weather elements affecting the departure of ring-necked ducks from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	15	temp., 1900	0.076	-22.92	4.98
2	30	pressure - 48 hrs.	0.042	9.34	2.90
3	6	light snow, 1900	0.018	847.14	405.03
		Intercept		-25,695.50	
		N<AV:			
1	27	temp. - 24 hrs.	0.280	3.04	0.41
2	31	temp. - 48 hrs.	0.023	2.27	0.40
3	32	tail wind speed - 48 hrs.	0.019	1.98	0.47
4	2	visibility in miles	0.007	0.52	0.09
5	16	temp. change - 6 hrs.	0.007	2.82	0.79
6	33	cross wind speed - 48 hrs.	0.005	-1.54	0.59
7	4	mod. rain, 1900	0.004	38.40	13.19
8	6	light snow, 1900	0.004	67.89	25.37
9	29	cross wind speed - 24 hrs.	0.003	-1.39	0.60
		Intercept		-460.60	

*Regression coefficient for the indicated variable at the final step

Table 16. Relative importance of weather elements affecting the departure of canvasbacks from the region of Fargo, North Dakota, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	27	temp. - 24 hrs.	0.086	-42.02	6.97
2	32	tail wind speed - 48 hrs.	0.049	-37.19	9.47
3	14	pressure change - 48 hrs.	0.013	-5.23	2.71
		Intercept		2,551.73	
		N<AV:			
1	31	temp. - 48 hrs.	0.317	2.57	0.57
2	15	temp., 1900	0.034	4.12	0.58
3	11	pressure, 1900	0.012	0.59	0.19
4	32	tail wind speed - 48 hrs.	0.007	1.45	0.37
5	20	wind speed, 1900	0.005	1.56	0.68
6	16	temp. change - 6 hrs.	0.004	3.92	1.01
7	17	temp. change 24 hrs.	0.008	-1.54	0.64
8	30	pressure - 48 hrs.	0.002	0.64	0.20
9	21	tail wind speed, 1900	0.003	1.11	0.43
10	28	tail wind speed - 24 hrs.	0.003	1.04	0.44
		Intercept		-4,049.29	

*Regression cbefficient for the indicated variable at the final step

Table 17. Relative importance of weather elements affecting the departure of canvasbacks from the region of Peoria, Illinois, 1948-1968 (See text for definition.)

Regression step no.	Weather variable No.	Weather variable Description	Increase in R^2	Coeff.*	S. E.
		N>AV:			
1	15	temp., 1900	0.083	-82.47	30.19
2	28	tail wind speed - 24 hrs.	0.028	-120.10	37.23
3	1	ceiling height, 1900	0.022	1.58	59.98
4	27	temp. - 24 hrs.	0.017	-60.78	29.35
		Intercept		7,173.32	
		N<AV:			
1	15	temp., 1900	0.317	24.74	1.01
2	18	temp. change - 48 hrs.	0.050	-9.30	1.83
3	32	tail wind speed - 48 hrs.	0.020	9.87	1.84
4	6	light snow, 1900	0.016	-408.16	99.21
5	2	visibility in miles	0.006	1.54	0.35
6	23	cross wind speed, 1900	0.007	-7.16	2.31
7	4	mod. rain, 1900	0.004	138.25	51.31
8	17	temp. change - 24 hrs.	0.003	-5.97	2.14
9	28	tail wind speed - 24 hrs.	0.003	5.38	2.08
10	30	pressure - 48 hrs.	0.003	1.56	0.68
		Intercept		-6,330.84	

*Regression coefficient for the indicated variable at the final step

Larger-than-average mallard departures from the Peoria area were of greater magnitude with declining temperatures, moderate falling snow, and winds that were unfavorable (Table 5). Such poor weather conditions for flying suggest forced departures by low-pressure areas west of Peoria.

The smaller-than-average mallard departures from Peoria are correlated with high temperatures and following winds (Table 5). Light snow tended to hold departures down. These conditions are consonant with an approaching warm high-pressure system, with fair weather and favorable flying conditions.

Pintail.--Weather conditions had very little effect upon larger-than-average departures of pintails from the Fargo area (Table 6). Continuing low temperature and low pressure were most important to departure of smaller-than-average numbers.

Departures of pintails from the Peoria area were also little affected by weather factors (Table 7). Larger departures were slightly correlated with poor flying conditions (adverse wind and moderate snow), and the small departures with humidity, tail winds, and rising temperatures.

Green-winged Teal.--The larger departures of green-winged teal from the Fargo area were little influenced by weather factors (Table 8). Slight correlation with high temperature the previous day and favorable tail winds 2 days earlier suggest that good flying conditions tended to increase departures.

Unlike previous species, the smaller-than-average departures of green-winged teal were correlated with generally adverse weather conditions in the Fargo area. Low temperatures and pressure over the previous 2 days were related to increased movements. Rains tended to be a slight deterrent to departures. The weather elements associated with these departures are typical of the back side of storms.

Although the departures of the larger numbers of green-winged teal from the Peoria area indicated little correlation with weather (Table 9), the elements that were correlated, light snow and falling temperatures, indicated poor flying conditions. Smaller departures of green-winged teal from the Peoria area were not greatly influenced by weather (Table 9), the most important elements consisting of rising temperature, low pressure on the previous day, and light snow.

Wigeon.--Weather factors exerted only a small influence on larger-than-average departures of wigeon from the Fargo area (Table 10). The high ceiling and other weather conditions indicated that somewhat more departures occurred under fair weather resulting from high pressure.

On the other hand, smaller-than-average departures were correlated with a variety of weather conditions: low temperature, temperature

increase over 2 days, and low pressure. These elements do not fit any clear-cut weather pattern.

Departures of wigeons from the Peoria area occurred under weather conditions similar to those at Fargo but with lower correlation (Table 11). Cool moist weather was associated with the smaller-than-average departures.

Lesser Scaup.--Weather factors in the Fargo area accounted for only a small proportion of the variability in departures of lesser scaups (Table 12). Moderate snowfall and rising pressure during the previous 24 hours affected the larger departures. These conditions may occur a day after passage of a cold front. Smaller flights were only very slightly correlated with weather.

Departures of lesser scaups from the Peoria area were influenced more by weather than were those in the Fargo area (Table 13). The larger departures were correlated with low dew points, adverse winds during the previous day, and clear skies. These data suggest that departures were influenced by cool, dry air masses moving into the area from approaching high centers, bringing favorable flying conditions.

Below-average-size departures of scaups from the Peoria area were related to continuing high temperature, favorable tail winds, good visibility, and declining pressure. Such weather conditions often prevail between the passage of cold fronts.

Ring-necked Duck.--At Fargo, weather factors had a slight correlation with departures for this species (Table 14). Reductions in visibility and falling temperatures were associated with departures of above average size. Such conditions occur behind cold fronts. The smaller departures at Fargo were even less correlated with weather factors.

In the Peoria area, there was a moderate correlation between weather conditions and ring-necked duck departures (Table 15). Low temperatures and light snow were correlated with the larger departures, indicating poor flying conditions. Departures of below-average numbers from the Peoria area occurred with more favorable flying conditions: continuing high temperature, favorable tail winds, and good visibility (Table 15).

Canvasback.--Larger-than-average departures of canvasbacks from the Fargo area were correlated with poor flying conditions (Table 16). Temperatures were low the previous day, and pressure declined during the previous 2 days; tail winds that had been adverse were perhaps nominal or favorable at the times of departure. These findings suggest that larger departures came a day after cold fronts.

Departures of below-average numbers of canvasbacks were moderately correlated with weather conditions (Table 16). Continuing high temperatures and high pressures plus favorable tail winds point to good flying

conditions such as may be found near the center of a warm high-pressure area.

Weather conditions were as great a factor in larger-than-average canvasback departures from the Peoria area (Table 17) as they were from the Fargo area. Low temperatures and a negative coefficient, which indicated an adverse wind the previous day, suggest that more departures probably occurred immediately behind the passage of cold fronts.

Departures of smaller-than-average numbers of canvasbacks from the Peoria area were moderately correlated with weather factors (Table 17); high temperatures were most important. Decreasing 48-hour temperature change and favorable winds 2 days previously also contributed to departures.

Evaluation of Multiple Regression Findings

It is apparent from this study that the relationship between short-term weather conditions and migrational departures of various species of ducks is a most complex one. The modelling of duck departures as a function of the assemblage of weather elements varies from poor to mediocre (Tables 2 and 3). At best only 25 to 50 percent of the variance of waterfowl departures is accounted for by the weather parameters fitted; in several species it is as low as 4 to 10 percent.

There appears to be a number of explanations for the low correlation of duck departures to measured weather elements:

1. Our estimation of the proportion of the departures that occurred on a particular day between periodic censuses may be subject to varying degrees of error.

2. Ducks may be influenced most by weather conditions that initiate departures from fall staging areas on their breeding grounds. Once underway in migration, ducks may be less motivated in their movements by local weather factors than they were at the start of their passage southward.

3. Environmental factors other than the weather parameters considered may influence the departure of ducks from migration areas in the fall. Food shortages, water-level changes, and pressure of hunters have been observed to result in premature departures of ducks from the Illinois and Mississippi River Valleys.

4. Physiological factors as well as weather factors influence the departure of birds in migration. The annual cycle of bird behavior is under the control of the pituitary gland modified by the timing of fat deposition essential to prolonged flight. As their migration period approaches, birds exhibit increasing unrest at night. Many departures of

ducks may result from their disposition to migrate rather than the influence of particular weather conditions. We have numerous records of autumn duck passages occurring when the weather was warm and the winds adverse. Such events were most often observed in September and October; but they extend, on a lesser scale, into November. Although most passages are of small magnitude, radar and visual observations indicate that rarely is there a night during the height of the migration period (late October and early November) when ducks are not in migration.

5. The assumption of a linear (first order) relationship may be in error on several counts. The difference in sign of several coefficients between the N>AV and N<AV categories indicates a discontinuity that may be explained by a threshold hypothesis. Combinations of weather elements may have to reach some integrated "value" to provide a stimulus for major movements. The magnitude of movements above this threshold is obviously quite differently related to weather conditions than movements below the threshold. Second, there is no real evidence that within these categories the responses are in fact linear. A complex interaction of many interrelated weather factors could easily affect movements. A first-order regression model would fail to detect many such effects, and no method of treating such relationships is readily available.

6. It is likely that one reason for the lower correlation for most N>AV and for N<AV duck departures is the result of a depletion effect following a large departure. That is, when the departure threshold is exceeded on a given night a large exodus results, which is not repeated at the same intensity for subsequent thresholds of similar severity. The larger the <u>forced</u> departure, the fewer waterfowl would remain to depart in similar weather later. At Fargo, duck departures of N<AV were 3.9 times more frequent than departures of N>AV. At Peoria there were 4.2 times as many departures of N<AV than of N>AV. The greater frequency of the N<AV departures indicates that the depletion effect is so large as to affect number of departures for several days.

All six explanations probably account to a greater or lesser degree for the various poor to mediocre correlations of weather elements with the departures of ducks. However, the last four explanations are believed to be the more important ones. In speculated order of importance, they are: (1) the physiological factor, (2) environmental factors other than the weather factors considered, (3) the depletion effect, and (4) the nonlinearity of the relations between weather factors and migration movements.

In addition, it is important to bear in mind that correlation is not synonymous with causation. Some weather elements may be highly correlated with movements simply because the movements occur, owing to other causes, at the time when these weather elements have certain values. For example, large movements of canvasbacks at times of low temperatures can mean either that low temperatures cause the movements or that movements occur (for nonweather-related reasons) at a time when temperatures are low. Field observations seldom can resolve such questions.

Relationship to Frontal System

Weather maps were studied in relation to dates that waterfowl were observed arriving or departing the Illinois and Mississippi River Valleys. The position of various weather fronts, high- and low-pressure areas, and related weather conditions were evaluated.

The occurrence of departures of all species of ducks from the Fargo and Peoria areas in relation to various frontal systems, as well as to times when fronts were not present, are shown in Table 18. Surprisingly, over one-half of the duck departures from both the Fargo and Peoria areas occurred when weather fronts were not located in a position to influence their movements. Thus, most duck departures occurred under weather conditions that prevailed between the passage of frontal systems.

Table 18. The frequency of duck departures of all species from the Fargo, North Dakota, and Peoria, Illinois, areas in relation to various weather fronts and an absence of fronts as well as the status of frontal systems when no waterfowl departures were detected, 1961-1969

	Percent of departures		
Type of front	From Fargo	From Peoria	None detected
Cold	21.04	23.84	18.80
Occluded	7.93	4.65	8.38
Stationary	11.28	11.63	10.26
Warm	4.57	4.07	4.62
Fronts Absent	55.18	55.81	57.94
Total	100.00	100.00	100.00

Another surprising finding was that among the four types of fronts—cold, occluded, stationary, and warm—there appeared to be a relatively small tendency to depart with the passage of cold fronts. The frequency of ducks departing with various types of frontal systems at Fargo and Peoria was similar to the frequency of occurrence of these frontal systems when no departures were detected (Table 18). With cold fronts, however, there were somewhat more cases with departures, from both Peoria and Fargo, than there were cases with no departures detected. Warm and occluded fronts showed fewer departure than no departure cases. With stationary fronts (often very slowly moving cold fronts, with comparable weather) there were also more departures than not, but fewer than with cold fronts. Therefore, it appears that the passage of cold fronts played a minor role in the departures of most duck flights. However, we have not evaluated the effect of cold fronts on the magnitude of waterfowl

departures. It may well be that the larger departures of waterfowl occur with cold fronts and the smaller departures with other types of fronts as well as between fronts.

Position of Cold Fronts

The position of cold fronts that were concomitant with departures of ducks from the Fargo area is shown in Figure 1. The position of 110 cold fronts averaged about 75 miles northeast of Fargo. The inner trapezium encloses the positions of one-third of the cold fronts. One-third of the departures occurred with cold fronts spread over 160 miles of longitude and 80 miles of latitude. The outer trapezium embraces the nearest point to Fargo of two-thirds of the cold fronts on the day that ducks departed the region. Location of these cold fronts embracing two-thirds of the duck departures extended over 350 miles of longitude and 240 miles of latitude. Most of the duck departures at Fargo occurred with the cold fronts east and slightly to the north.

The median point for the nearest position of cold fronts on the day of duck departures from the Peoria area (Fig. 2) was 65 miles northwest of that city. The position of one-third of the cold fronts is shown by the inner trapezium, which extends over 115 miles of longitude, mostly east of Peoria, and 175 miles of latitude, mostly to the north.

Two-thirds of the cold fronts on the day of duck departures in the Peoria area were embraced by the outer trapezium (Fig. 2). It extends over 335 miles of longitude and 490 miles of latitude.

Although only from one-fourth to one-fifth of the departures of ducks were considered related to cold fronts (Table 18), the proportion shrinks even lower when the positions of the cold fronts are considered (Figs. 1 and 2). The positions of the cold fronts at Fargo indicate that only about two-thirds of the local duck departures considered related to the passage of these fronts (Table 18) occurred concomitantly with the fronts. The remaining third of the departures occurred when the fronts were probably too far from the area of departure to have any influence. Only one-half of the duck departures at Peoria appear related to the cold fronts considered potentially influential (Table 18). One-half of the fronts were at such distances from the area of departure that it seems unlikely that they exerted any direct influence.

Thus, the proportion of the duck departures actually associated with cold fronts (Table 18) shrinks from 21 to 14 percent for the Fargo area and from 24 to 12 percent for the Peoria area.

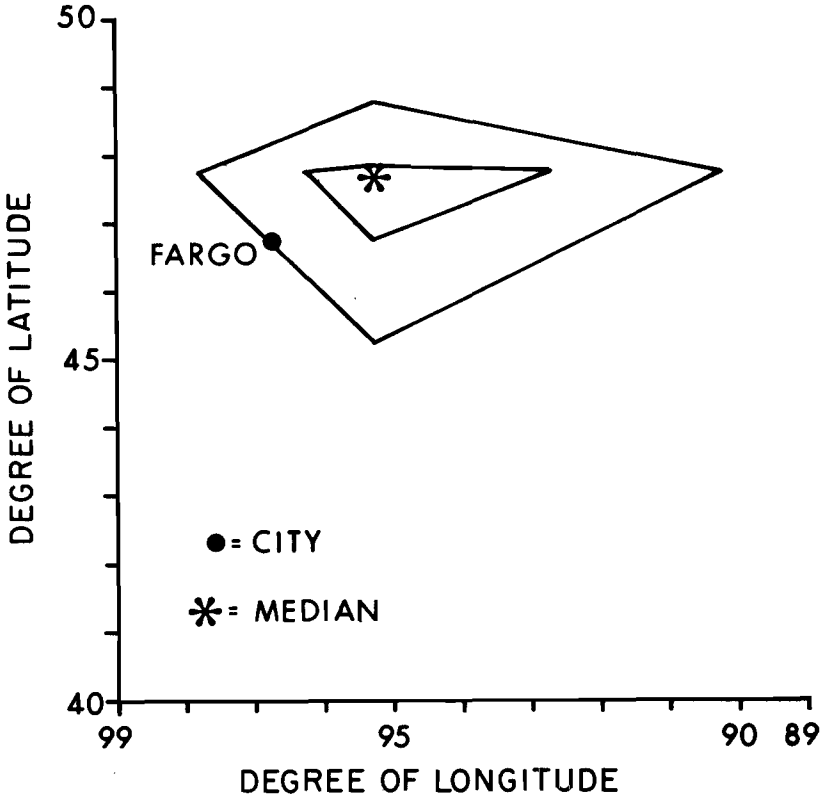

Fig. 1. The location of cold fronts relative to duck departures from the Fargo, North Dakota, area, 1961-1969. The inner trapezium delimits the longitudinal and latitudinal distribution of one-third of the cold fronts at their point nearest Fargo; the outer trapezium delimits the distribution of two-thirds of the cold fronts.

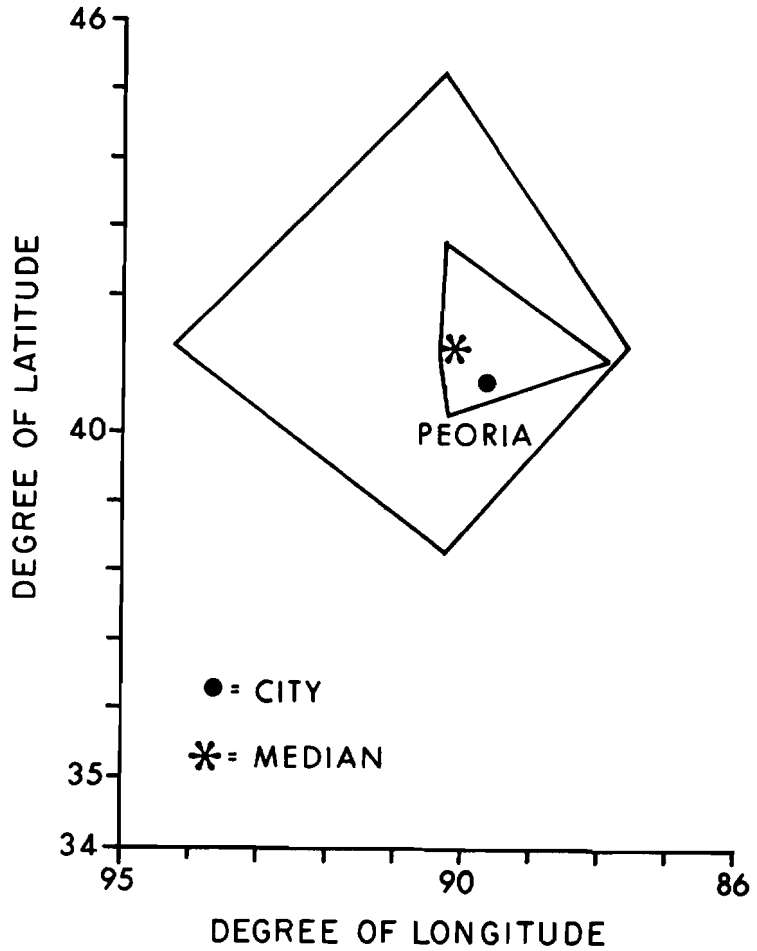

Fig. 2. The location of cold fronts relative to duck departures from the Peoria, Illinois, area, 1961-1969. The inner trapezium delimits the longitudinal and latitudinal distribution of one-third of the cold fronts at their point nearest Peoria; the outer trapezium delimits the distribution of two-thirds of the cold fronts.

Fargo.--The positions of low- and high-pressure areas in reference to departure of ducks from the Fargo area are shown in Figures 3 and 4. The median position of low-pressure centers on the day of duck departures was about 250 miles north-northeast of Fargo (Fig. 3).

The range of the low-pressure centers at the time of duck departures at Fargo covered a much greater area than that of the cold fronts. One-third of the departures occurred on days the low centers were located within a trapezium encompassing 350 miles of latitude and 260 miles of longitude. The trapezium embracing low-pressure centers at the time of two-thirds of the departures covers 700 miles of latitude and 830 miles of longitude.

The median position of high-pressure centers was located 280 miles north-northwest of Fargo (Fig. 4). As in the case of the low-pressure centers, they were in many different locations on the days of duck departures from Fargo. The trapezium encompassing high-pressure centers at the time of one-third of the duck departures extended over 250 miles of latitude, entirely north of Fargo, and 375 miles of longitude, almost entirely to the west. Two-thirds of the departures occurred with the high-pressure areas ranging over 700 miles of latitude and 1,000 miles of longitude.

Peoria.--The median position of low-pressure centers on the day of duck departures from the Peoria area was 500 miles to the north-northwest (Fig. 5). The trapeziums embracing low-pressure locations when one-third and two-thirds of the departures that occurred extend over a larger region at Peoria than at Fargo. Most of the low-pressure centers were north and west of Peoria.

High-pressure centers for duck departures in the Peoria area were in about the same positions latitudinally (Fig. 6) as low-pressure centers, but they were generally located farther west. The median position of high-pressure areas was about 600 miles northwest of Peoria when duck departures occurred. As shown by the trapeziums embracing both one-third and two-thirds of the departures, the high-pressure centers were located over a great range of latitude and longitude but almost always to the north and west of Peoria.

The geographic location of high- and low-pressure centers in relation to duck departures varied a great deal more than did the geographic location of the cold fronts. Thus, weather conditions associated with cold fronts per se appeared to be more closely associated with duck departures than weather conditions associated with high- and/or low-pressure areas per se.

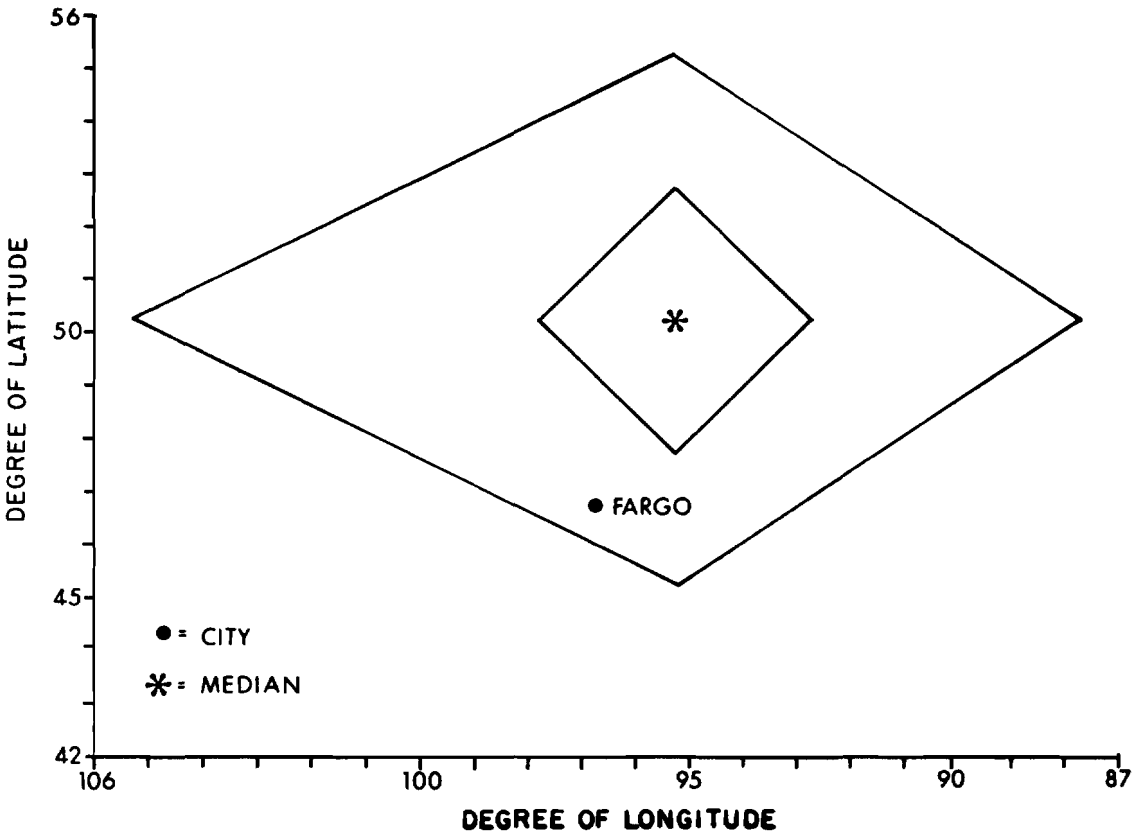

Fig. 3. The location of low-pressure centers relative to duck departures from the Fargo, North Dakota, area, 1961-1969. The inner trapezium delimits the longitudinal and latitudinal distribution of one-third of the centers from Fargo; the outer trapezium delimits the distribution of two-thirds of the low-pressure centers.

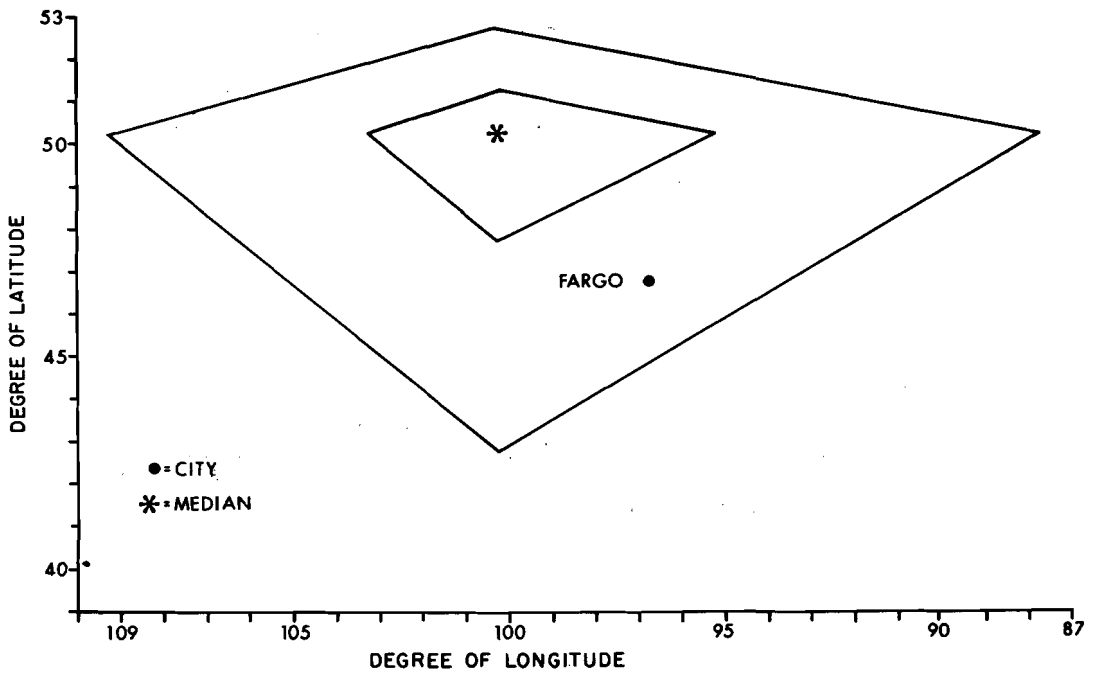

Fig. 4. The location of high-pressure centers relative to duck departures from the Fargo, North Dakota, area, 1961-1969. The inner trapezium delimits the longitudinal and latitudinal distribution of one-third of the centers from Fargo; the outer trapezium delimits the distribution of two-thirds of the high-pressure centers.

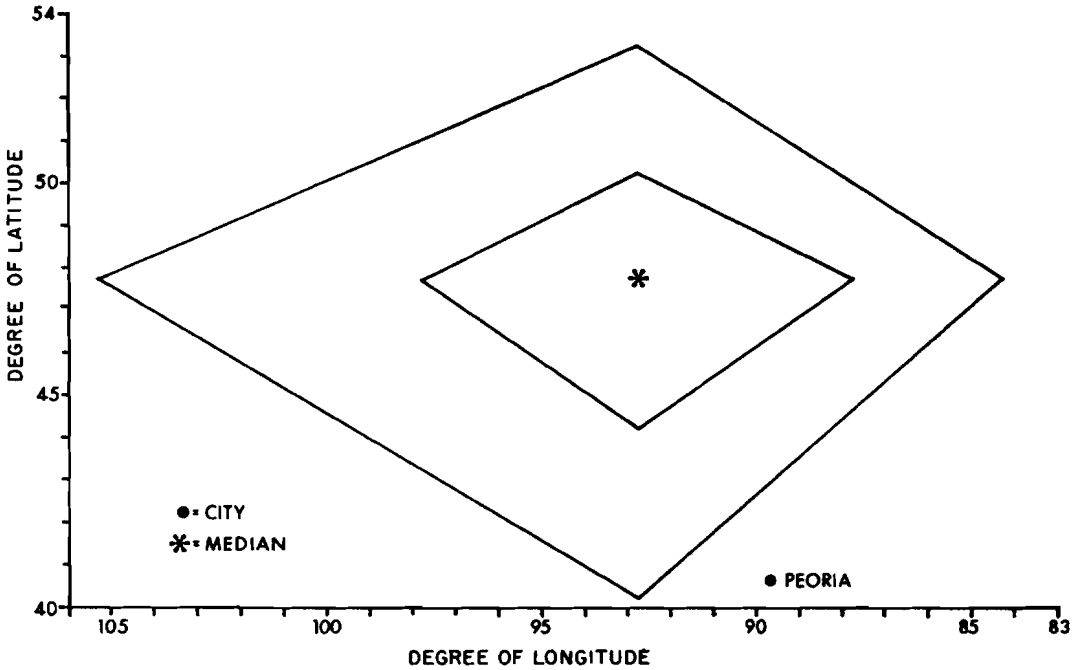

Fig. 5. The location of low-pressure centers relative to duck departures from the Peoria, Illinois, area, 1961-1969. The inner trapezium delimits the longitudinal and latitudinal distribution of one-third of the centers from Peoria; the outer trapezium delimits the distribution of two-thirds of the low-pressure centers.

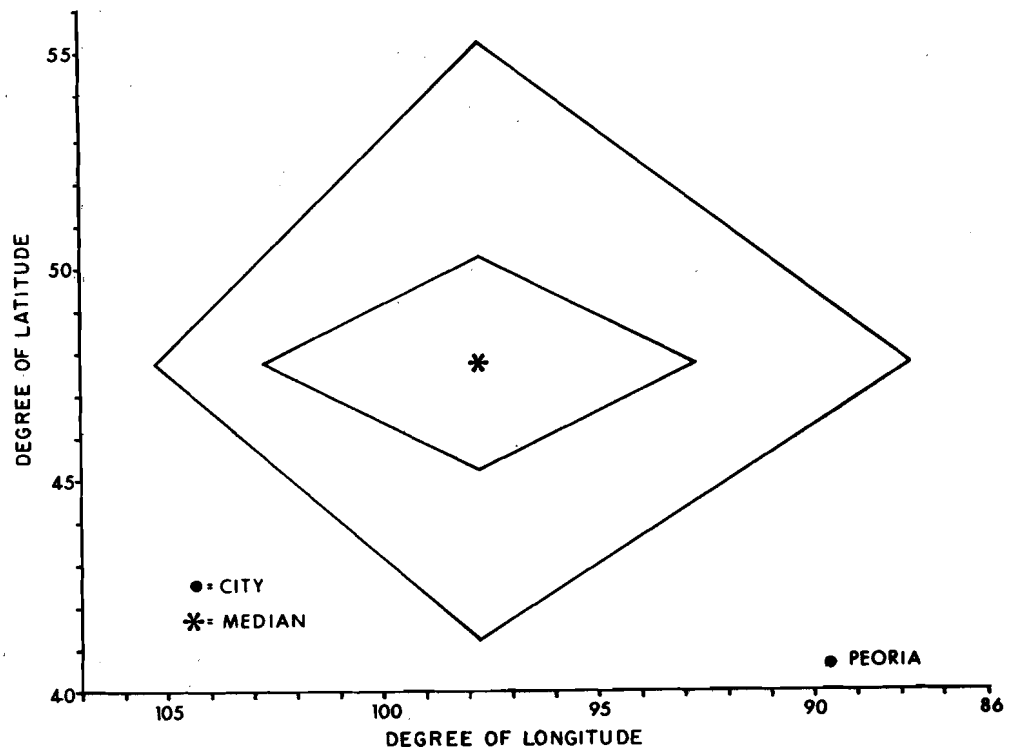

Fig. 6. The location of high-pressure centers relative to duck departures from the Peoria, Illinois, area, 1961-1969. The inner trapezium delimits the longitudinal and latitudinal distribution of one-third of the centers from Peoria; the outer trapezium delimits the distribution of two-thirds of the high-pressure centers.

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DISCUSSION

This study indicates that weather factors do not play as important a proximate role in motivating the departure of waterfowl as previously conceived. Some of the convictions as to the importance of weather in waterfowl migration developed in part from the reporting on weather conditions that induced mass departures of birds (Hochbaum 1955, Bellrose 1957, Bellrose and Sieh 1960).

Mass departures of waterfowl are undoubtedly the result of weather conditions that reduce availability of food by the freezing of shallow water areas and by snow covering upland feeding grounds. Mass departures of waterfowl almost invariably originate in Canada and, once initiated, continue over several days and for hundreds of miles.

In the present study, the mass departures of waterfowl from breeding-ground areas had a minimal influence on the evaluation of waterfowl migration in relation to weather conditions. First, mass migration flights composed no more than 1 to 2 percent of all movements occurring. Thus, data from the bulk of the departures overwhelmed the data associated with mass departures. Second, we did not study the relationship of weather to departures of waterfowl from breeding-ground areas. Fargo is on the southeast edge of vast breeding grounds for ducks that extend hundreds of miles farther to the northwest. Weather data over such a large area has great geographical variability in addition to the temporal variability found in data at one location. In addition, the movement data do not show the times of initiation of migrations from breeding localities.

The present study embodied departures of ducks that had already migrated part of the way to their winter haunts. The back-dating of duck arrivals in Illinois by 36 hours or more rather than 12 hours might provide a means of collating weather and duck departures from breeding ground areas. Possibly better correlation for the actual migration initiation probably would be offset by the uncertainty of the assumptions involved.

There are two fundamental kinds of influence affecting the timing of bird migration, exogenous and endogenous. Exogenous factors are environmental in nature, e.g., weather and food; endogenous factors are physiological in nature, e.g., chronological sequence in annual behavior patterns under control of the pituitary, subject to modification by the photoperiod or other exogenous factors.

The present study suggests that, among those species of ducks studied, endogenous factors exerted a greater influence on initiating migration than was previously believed, relative to exogenous factors. The early and midseason migrants (pintail, green-winged teal, wigeon, lesser scaup, and ring-necked duck) in particular showed low correlations with weather

factors, indicating that endogenous factors may have been largely responsible for their departures.

Weather elements were fairly highly correlated with the departures of late-season migrants (mallards and canvasbacks). Even in these species, however, endogenous factors appeared to be more important than weather.

For these late-season migrants, rather poor flying conditions prevailed for larger-than-average departures. Larger-than-average departures under poor flying conditions suggest that adverse weather forced more ducks to leave than usual for the date. On the other hand, smaller-than-average departures of late-season migrants were related to generally favorable flying conditions as if they were under no particular duress from weather conditions at the times of departure, but selected good weather to continue a migration already initiated.

All three of the early-migrating species studied--pintail, green-winged teal, and wigeon--responded similarly to weather. Their highest correlation with weather was with smaller-than-average departures from the Fargo area: the highest was for wigeon (42.7 percent), and the lowest was for pintails (28.1 percent). The correlations for both larger- and smaller-than-average departures for all three species from the Peoria area were low; the highest being only 9.1 percent. Therefore, the weather conditions associated with smaller-than-average departures from the Fargo area are the most significant. The conditions favoring departure were low temperatures and pressures for all three species, and low temperature 2 days before for two species.

Midseason migrants, lesser scaup and ring-necked ducks, departing Fargo were little influenced by weather conditions. Departures in below-average numbers from Peoria were correlated with continuing high temperatures and favorable tail winds; conditions for flying then would be good. There was no general agreement in the weather factors correlated with the larger-than-average departures of scaups and ring-necked ducks.

Most larger-than-average departures of all species occurred under the duress of adverse weather conditions. On the other hand, the more frequent smaller-than-average departures occurred under weather conditions favorable for migration.

Temperature and barometric pressure were the weather elements that appeared most frequently with a reasonably good correlation in the analysis of the movements of the various duck species.

CONCLUSIONS

The present study indicates that it would be difficult to forecast the magnitude of waterfowl passage in the Midwest based upon synoptic charts or other weather information available to aircraft controllers. This nebulous situation appears to prevail for three principal reasons: (1) the frequency of passage as a result of endogenous (physiological) factors; (2) the depletion factor that leaves a lag after large departures even though subsequent weather factors are similar; and (3) limitations of the study, both as to available weather data and as to knowledge of total migration movements.

Although 21 years of field data and thousands of hours of effort in analysis of these data went into this study, further analysis is desirable. First, an attempt to relate weather to initiation of migration from breeding grounds, particularly on the basis of synoptic weather patterns, might prove illuminating. Second, better correlations might be obtained by separating the data into three time periods, in order to reduce variance caused both by seasonal changes and by the tendency of the duck species to separate into early, midseason, and late migrating groups. Third, further refinements of the statistical treatment are possible, for example, taking account of the "depletion" effect discussed above, and studying residuals to determine if interaction and higher-order terms would improve the fitted equation. Neither time nor funds were available to accomplish these additional analyses under the present study.

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