48 The Influence of Local Weather on Autumn Migration of Peregrine Falcons at Assateague Island

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Observations of diurnal hawk migration have been well documented in many regions of the world (Richardson 1978, Newton and Chancellor 1985). Many studies of the relationship between counts of migrating hawks and weather have been conducted where migrants become concentrated in the northern hemisphere, including those of Mueller and Berger (1967b) for Sharp-shinned Hawks, Haugh (1972) for a variety of species, Alerstam (1978) for the Common Buzzard, Western Honey Buzzard, and European Sparrowhawk, and Titus and Mosher (1982) for other species. Consequently, we have some understanding of effects of local weather on visible migration of common holarctic raptors. This is not the case for migrant Peregrine Falcons, although they have been counted annually at many locations (Allen and Peterson 1936, Broun 1939, Mueller and Berger 1961, Hofslund 1966, Edelstam 1972, Evans and Lathbury 1973, Dekker 1984). The numbers counted have usually been too few for comparison with weather data; however, at Assateague Island, Maryland/Virginia, Peregrines have been counted in sufficient numbers to allow analyses of the effects of weather on counts.

We studied long-distance migrants from natal areas hundreds of kilometers to the north in the arctic regions of central Canada and Greenland (Yates et al. Chapter 44). Local weather en route probably causes only short-term responses by the migrants but identification of such influences may improve the comparison of counts among sites or years. By understanding and correcting for the influences of local weather on autumn counts, we also gain insight into the utility of these counts as indicators of population levels (Svensson 1978, Hussell 1981).

METHODS

We studied the autumn migration of Peregrines from 1970-84 at Assateague Island, Maryland/Virginia, a barrier island oriented north-northeast to south-southwest. Observation methods following those of Ward and Berry (1972) began as early as 17 September and continued daily as late as 25 October, but the only data used were from 21 September-18 October, when 90% of the migration occurs (cf. Alerstam 1978). Resident Peregrines, resightings and recaptures were eliminated from analyses (Ward et al. Chapter 45). Local weather data and migration counts for 1970-81 were used in analyses. Hourly wind direction, wind speed and cloud cover, and daily rain and temperatures were collected from a weather station on Assateague Island (Table 1). Barometric pressure data were taken from daily weather maps for Salisbury, Maryland.

Daily counts were pooled into three migration intensity categories as follows: (1) 0-1 bird observed per day, (2) 2-10 birds observed per day, and (3) 11 or more birds observed per day. As the numbers observed increased throughout the 12-year study (Ward et al. Chapter 45), we standardized the transformed daily count data to eliminate the year effect by calculating a "Z" score based on the number of birds observed within that year. Two migration intensity categories were created from the standardized counts for categorical analyses: (1) lower-than-average daily count ($Z<0$), and (2) equal-to- or greater-than-the-average daily count ($Z\geq0$). Two sets of analyses were conducted, the first with actual counts and the second with standardized counts. These and other approaches have been used in migration/weather studies (Mueller and Berger 1961, Alerstam 1978, Beason 1978, Richardson 1978, Titus and Mosher 1982).

Spearman rank correlations (Zar 1974) were conducted between the daily counts, transformed daily counts, and all weather variables (Table 1). The cosines of the 16 wind directions were derived according to a standardized scheme so that these variables could be evaluated on a linear scale. We termed these wind direction effect variables. Log-likelihood ratio Chi-square analyses (Zar 1974) were used to compare categorical weather variables with categories of migration intensity. The 16 wind directions were pooled into eight wind directions for log-likelihood ratio analyses. Correlation and log-likelihood ratio Chi-square analyses were also conducted with the daily counts of birds that were flying when first sighted, and also with those that were not flying (e.g., perched, actively hunting, eating). These two sets of analyses were conducted to determine whether local weather might have been associated with active migration (flying) versus any other nonmigratory behavior.

TABLE 1. Summary and definitions of local weather variables available for analysis.

Variable	Method of measurement
Wind direction	Obtained hourly as 16 directions or calm
DMORN	The rounded daily mean of hourly wind directions from 0600 – 1300
DAFTER	The rounded daily mean of hourly wind directions from 1300 – 1900
DDAY	The rounded daily mean of hourly wind directions from 0600 – 1900
DNIGHT	The rounded nighttime mean of hourly wind directions from 2000 – 0600
Wind direction effect	The cosine of the mean wind direction assuming a NNE to SSW migration path (the orientation of the island). This scales the data from −1.0 (opposing winds) to +1.0 (following winds)
DMORNEFF DAFTEREFF DDAYEFF DNIGHTEFF	Same time periods as for wind direction
Wind speed	Obtained hourly in miles per hour
SMORN SAFTER SDAY SNIGHT	Same time periods as for wind direction rounded to the nearest mile per hour
Cloud cover	Obtained hourly according to the following scale: 0 = clear or less than 0.1 cloud cover 1 = scattered clouds or 0.1 – 0.5 cloud cover 2 = mostly or 0.6 – 0.9 cloud cover 3 = overcast 4 = fog
CMORN CAFTER CDAY CNIGHT	Rounded to the nearest whole number; same time periods as for wind direction
MAXT	Maximum temperature for the 24 h time period (00 hrs to 2400)
MINT	Minimum temperature for the 24 h time period (00 hrs to 2400)
T1700	Temperature at 1700
RAIN	Measured as inches of precipitation. In 1970-71 taken from daily weather maps, Salisbury, Md; 1972-81 taken from a rain gauge, Assateague State Park
BAR	Barometric pressure in millibars; taken from daily weather maps, Salisbury, Md, 0700 EST
BARHL	Barometric pressure at Salisbury, 0700 EST higher or lower than or the same as at 0400 EST
BARTEND	Barometric pressure tendency at Salisbury, 0700 EST; nine codes as described on standard NOAA weather maps

Stepwise discriminant function analysis (DFA, Hair et al. 1979) was conducted to determine: (1) whether levels of migration intensity could be predicted from some subset of local weather variables, and (2) which variables were most correlated with the data in deriving the canonical variates. Prior probabilities were based on group sample sizes. The test of homogeneity of covariance matrices was set at default ($P<0.10$).

RESULTS

Observations were made on 313 days over the 12-year period. On 62 of these days (19.8%) no Peregrine Falcons were observed. The maximum daily count was 65, and 30 or more Peregrines were observed on only 12 (3.8%) days.

Temperature, wind speed and wind direction effect variables were not correlated with counts of migrants (Table 2). Only two of 14 local weather variables considered in the correlation analyses were significant when all years were pooled. More Peregrine Falcons were observed when rain increased and barometric pressure decreased. The total number of migrants was positively correlated with the standardized number of migrants ($r_s=0.81$, $n=313$, $P<0.001$); the lack of perfect correlation can be attributed to the yearly variation and the increase in

TABLE 2. Spearman rank correlation coefficients among numbers of migrant Peregrine Falcons and local weather variables at Assateague Island, 1970-81.

	Total no. of migrants seen daily		Standardized total no. of migrants	
Weather variables[a]	r	Significance[b]	r	Significance[b]
MAXT	0.012	NS	0.043	NS
MINT	0.057	NS	0.054	NS
TI700	0.005	NS	0.043	NS
RAIN	0.167	**	0.125	*
BAR	-0.270	***	-0.187	***
BARTEND	0.022	NS	0.028	NS
SMORN	0.011	NS	-0.010	NS
SAFTER	0.042	NS	-0.013	NS
SDAY	0.026	NS	-0.015	NS
SNIGHT	-0.029	NS	0.068	NS
DMORNEFF	0.012	NS	-0.047	NS
DAFTEFF	0.006	NS	0.002	NS
DDAYEFF	0.008	NS	-0.016	NS
DNIGHTEFF	0.019	NS	-0.040	NS

[a] Weather variables as in Table 1.
[b] Levels of significance: NS = not significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

annual counts. Of 168 pairwise correlations within years, 13 were significant ($P<0.05$), which was not much more than chance error. In five of the 12 years, no weather variables were correlated with counts from that year. No correlations were significant in one direction one year and then significant in the opposite direction in another year.

Only three of 10 categorical weather variables were statistically related to the total counts of migrants (Table 3). Days with high migration counts occurred more frequently when barometric pressure was lower at 0700 hours than three hours earlier in the morning. Significantly more Peregrine Falcons were observed when cloud cover exceeded 60%. Conversely, fewer falcons were sighted when days were clear to partly cloudy. No significant results were found when the counts were partitioned into flying versus perching or hunting behaviors relative to weather.

Of 12 days when 30 or more migrants were observed, four days each occurred in 1979 and 1980 (Table 4). Local weather conditions were not the same on each date when peak flights occurred. Cloud cover on peak migration days was not different from that typically encountered throughout the study. Barometric pressure on six of these days was falling in the early morning, which was atypical. On 78% of 313 days with data, the barometric pressure was rising. Wind direction showed no apparent pattern with peak flight days. Both following (northeast) and opposing (south and southwest) winds were associated with large counts.

TABLE 3. Log-likelihood ratio Chi-squares among numbers of migrant Peregrine Falcons and local weather variables at Assateague Island, 1970-81.

Weather variables[a]	Total no. seen daily (3 categories)			Standardized total no. of migrants (2 categories)		
	χ^2	Degrees of freedom	Significance[b]	χ^2	Degrees of freedom	Significance[b]
BARHL	13.2	4	*	5.7	2	NS
BARTREND	19.6	16	NS	14.5	8	NS
DMORN	9.9	14	NS	7.3	7	NS
DAFTER	10.1	14	NS	1.6	7	NS
DDAY	5.5	14	NS	5.5	7	NS
DNIGHT	13.5	14	NS	13.0	7	NS
CMORN	15.0	6	*	4.6	3	NS
CAFTER	7.1	6	NS	2.6	3	NS
CDAY	13.7	6	*	3.3	3	NS
CNIGHT	4.7	6	NS	4.6	3	NS

[a] Weather variables as in Table 1.
[b] Levels of significance: NS = not significant; * = $0.01 < P < 0.05$.

TABLE 4. Dates and weather when 30 or more Peregrine Falcons were observed at Assateague Island, 1970-81.

Year	Date	No. observed	Rain (inches)	Mean daily wind speed (mph)	Mean daily cloud cover	Barometric pressure trend	Average daily wind direction
1971	6 Oct.	34	0.19	7	partly cloudy	missing	W
1978	5 Oct.	31	0.00	8	mostly cloudy	rising	E
1978	6 Oct.	34	0.01	5	partly cloudy	falling	SW
1979	3 Oct.	48	0.90	15	mostly cloudy	rising	W
1979	4 Oct.	32	0.00	8	clear	rising	S
1979	7 Oct.	37	0.00	13	cloudy	falling	W
1979	9 Oct.	58	0.15	12	mostly cloudy	falling	SW
1980	30 Sept.	41	0.00	16	mostly cloudy	falling	NE
1980	1 Oct.	65	0.08	11	cloudy	rising	NE
1980	10 Oct.	30	0.00	13	partly cloudy	missing	E
1980	11 Oct.	42	0.00	12	partly cloudy	falling	SW
1981	1 Oct.	36	0.00	12	partly cloudy	falling	S
Mean for all days (n = 313)		6.7	0.10	8	partly to mostly cloudy	rising	S and SW

Eighteen variables were inserted into the stepwise DFA, and five variables were selected by the procedure (Table 5). The covariance matrices were not homogeneous ($P=0.045$), so the procedure used a quadratic DFA. The derived canonical variates were significant, but the canonical correlation values were low. That barometric pressure had the highest correlation with the canonical variates supports the conclusion from univariate testing that high counts of migrants were most associated with low barometric pressure. The other variables were correlated with the canonical variates to lesser degrees. Classification rates were poor (Table 6). Both the low-count and high-count days were more often misclassified as medium-count days. A similar stepwise DFA was conducted with the "Z" score standardized counts that were grouped into low and high categories. The stepwise procedure selected only one variable (barometric pressure), and the results were not significant ($P>0.05$).

DISCUSSION

Significant associations between local weather and counts of Peregrine Falcons at Assateague Island were few. Unfortunately, other detailed studies of the association between weather and counts are lacking for this species. The only weather variable that we found to be consistently associated inversely with the daily counts was barometric pressure. Most notably, counts did not relate to wind direction and

TABLE 5. Results of a quadratic discriminant function analysis attempting to separate low, medium and high Peregrine Falcon migration counts based on local weather variables.

Statistic or variable	Discriminant function I	Discriminant function II
Statistic		
Canonical correlation	0.35	0.23
F-statistic	5.39, $P < 0.001$	3.86, $P < 0.01$
Variable[a]		
Barometric pressure	0.89	0.11
Temperature at 1700 hrs.	−0.15	0.64
Afternoon cloud cover	−0.39	0.37
Barometric pressure tendency	−0.32	0.43
Previous night wind speed	0.13	0.09

[a] Within class correlations between the canonical variates and the original variables.

TABLE 6. Classification of low, medium, and high Peregrine Falcon migration count dates from the discriminant analysis of Table 5.

	Predicted group		
Actual Group	Low	Medium	High
Low	27	55	2
Medium	15	122	9
High	13	26	16

Overall percent correctly classified = 57.9%
Percent correctly classified above chance = 22.6%

wind speed. Our results for 12 years do not support the empirical observations of Ward and Berry (1972) over two autumns, that light west winds might be associated with higher counts.

Numerous other raptor migration studies have found wind speed and wind direction to be strongly associated with counts of visible migrants (Ferguson and Ferguson 1922, Allen and Peterson 1936, Rudebeck 1950, Mueller and Berger 1961, 1967b, Haugh 1972, Alerstam 1978, Titus and Mosher 1982). Along the east coast of North America, northwest winds were shown to be strongly associated with peak hawk flights (Trowbridge 1895, Ferguson and Ferguson 1922, Allen and Peterson 1936, Stone 1937). Like Peregrine Falcon migration, Northern Harrier migration was not related to wind direction at Hawk Mountain, Pennsylvania (Haugh 1972), or along the Atlantic coast (Ferguson and Ferguson 1922). Dekker (1979) observed Peregrines migrating under a variety of weather conditions including strong headwinds. Based on a limited number of observations, Slack and Slack (1981) felt that Peregrines may alter their direction of migration depending on local weather.

Despite a lack of strong association between counts and local weather at Assateague Island, Peregrine Falcons did respond differently to small-scale local conditions on the island. Blowing sand on the beaches was a noticeable local effect of wind. Dry sand was blown on the beach at about 35 km per hour, and Peregrines seemed to avoid standing in such areas. This very localized condition only occurred along the beach front, often beginning around mid-morning. In fair weather, wind speed varied greatly on the island. By mid-morning a strong sea breeze was often blowing on the beach while only a light wind was blowing inland, behind the line of sand dunes paralleling the beach. Wind speed at various locations on the beaches was not measured.

We expected a relationship between weather and flying (migrating) versus perching or hunting (nonmigrating) behaviors, but no relationship was found. Peregrine Falcons may not alter their migrating versus nonmigrating behavior because of local weather at Assateague Island, or perhaps we could not detect the differences.

Although the Peregrine Falcons we observed were long-distance migrants, they were seldom observed using soaring flight as other hawks often do in migration. It thus seems logical that local weather would not be as important to Peregrine Falcons as to soaring hawks that depend on thermals. Note, however, that Peregrine Falcons have been detected using soaring and gliding flight in radio-telemetry studies of migration (Cochran 1985). Also, unlike other raptors that are reluctant to migrate over the ocean or will only make water crossings under optimal local weather (Kerlinger 1985), Peregrine Falcons can migrate far out to sea (Cochran 1985).

The weak but significant relationships of our counts with barometric pressure, rain and cloud cover indicates that continental-scale weather may influence Peregrine Falcon migration more than localized conditions. Not all Peregrine Falcons migrate quickly by Assateague Island. Many individuals spend a few days using the island for resting and hunting (Ward et al. Chapter 45), and some Peregrines have been found lingering between bouts of migratory flight. We need to explore the relationships between weather and the large numbers of resightings and retrappings of individuals within a season.

Our counts of Peregrine Falcons may be largely made up of birds exhibiting nonmigratory behavior after they have made landfall at the end of a "dogleg" flight down the Atlantic coast. If many of our counts were of nonmigratory birds, then the lack of association with local weather might be like that of some shorebirds, where radar studies indicate one pattern for migrating birds, but visual counts often associate higher numbers with inclement weather (Richardson 1979).

Examination of daily weather maps provides clues to the possible relationship between peak counts and the location of major weather systems. For example, high counts occurred on consecutive days during 1979 and 1980 (Table 4). On 2 October 1979 (one day prior to a high count day), low pressure systems were in central Canada, over Nova Scotia and over the Ohio Valley, with rain off the New England coast and in the Ohio Valley. On 29 September 1980, a large, low pressure storm was over James Bay, one was over Newfoundland, and another was just off the coast of South Carolina. Rain was present for the next few days as the result of two storm systems, one across eastern Canada, and another in the southeastern United States far out into the Atlantic Ocean. It is possible that inclement weather to the north, south and ocean sides of Assateague Island induces less migratory flight, producing high counts for a few days. These weather systems may not influence local weather at Assateague Island on dates with high counts, hence a lack of correlations between counts and local weather variables.

The passage of cold fronts may also be associated with high count dates, as occurred on 4-5 October 1978, 29 September 1980, and 9-10 October 1980. However, not all cold fronts produced higher counts.

A statistical approach is needed to determine whether broad weather systems are associated with visible counts of Peregrine Falcons. Because weather can influence the detectability of migrants (Evans 1966, Evans and Lathbury 1973, Kerlinger et al. 1985), the development of "correction factors" is needed to understand Peregrine Falcon migratory behavior and to use counts for detecting population trends.

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