

*J.H.M. Poirer*

# Bird migration forecasts for military air operations

by Hans Blokpoel



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### Abstract

A system for predicting density of bird migration was developed for use in reducing the number of in-flight bird-strikes (collisions between birds and aircraft) near Canadian Forces Base Cold Lake, in east-central Alberta. Migration forecasts were based on known migration density patterns, known correlations between weather and migration density, and the local weather forecast. During spring and fall 1970, routine forecasts of hourly densities of night-time migration were presented at the pilots' briefings for night flying. The migration forecasts were subsequently checked against actual densities obtained from time-lapse films of the scope of a surveillance radar. The accuracy of the density predictions for nights with accurate weather forecast was 96 per cent in spring, and 81 per cent in fall. This was sufficiently high for use in military flight planning. Results and shortcomings of the forecast system are discussed.

### Résumé

Un système de prévision de la densité des groupes d'oiseaux migrateurs a été mis au point en vue de

diminuer le nombre de collisions entre oiseaux et aéronefs, près de la base militaire de Cold Lake, dans la partie centre-est de l'Alberta. Les prévisions ont été basées sur les modes de densité migratoire connus, des corrélations connues entre conditions météorologiques et densité de migration, de même que sur les prévisions du temps local. Au cours du printemps et de l'automne de 1970, lors des exposés d'instruction pour les vols de nuit à l'intention des pilotes, on a communiqué des bulletins de prévision réguliers sur les densités de chaque heure des groupes en migration. Par la suite les densités prévues ont été comparées aux densités réelles enregistrées sur films chronophotographiques pris d'un écran de radar de surveillance. La justesse des prévisions des densités nocturnes, moyennant l'exactitude des données météorologiques, a été de 96% au printemps et de 81% à l'automne. Ce degré de précision est suffisant pour ce qui est de la planification des vols militaires. Les résultats et les imperfections du système font l'objet de discussions.

Collisions between birds and aircraft cause damage and sometimes fatal accidents in both civil and military aviation. Single-engine fighter aircraft, operating at high speed and low altitude, are particularly vulnerable to ingestion of birds (Gunn and Solman, 1968).

Bird-strikes at airfields can be minimized by eliminating birds from runways and vicinity (Solman, 1971). Bird-strikes en route are more difficult to prevent. Large flocks of migrating birds usually produce clear, distinct echoes on the screen of air traffic control radars (provided the flocks are above the radar horizon and not too far out), and might thus be monitored by properly trained air traffic controllers (Gunn and Solman, *op. cit.*). Small birds, flying singly or in loose association, produce echoes that are small, fluctuating in intensity, and thus much harder to pinpoint, especially during nights of heavy passerine migration when the scope is almost saturated with bird echoes. During such periods, aircraft cannot be guided around the birds and, until better methods are found, the only way to prevent bird-strikes during low-level exercises is to stop flying.

At the request of the Department of National Defence, a study was undertaken at Canadian Forces Base (CFB) Cold Lake (54°24'N lat., 110°17'W long.) in east-central Alberta to develop a system of forecasting periods of heavy bird movements. Films were taken of the screen of a surveillance radar near Cold Lake to study the effects of weather on migration density (Richardson, 1970; Richardson and Gunn, 1971), and migration density forecasts were made in the falls of 1968 and 1969 (Blokpoel, 1970a, b) using preliminary results (Richardson, pers. comm.).

This paper describes the forecast system used during spring and fall 1970, reports the results, and discusses its usefulness and shortcomings.

## Materials and methods

### Forecasting the density of bird movements

The Cold Lake radar films show normal (forward) migration (NW in spring and SE in fall), reverse migration (SE in spring and NW in fall), movements in other directions, and random bird activity. Flying personnel are especially interested in high density bird movements (migratory or otherwise). High densities are almost always caused by heavy migration in the normal direction. Reverse migration is almost invariably of low density, and local non-migratory movements involve relatively few birds. I use the convenient but incorrect term "migration forecasts" for the prediction of the density (or intensity) of all bird activity.

Migration forecasts were based on (1) known density patterns of bird movements, (2) known correlation between weather and the density of forward migration, and (3) the local weather forecast.

To express the hourly density or intensity of bird movements I used the arbitrarily chosen, ordinal, 0–8 density scale, briefly described by Fryers (1966). This method uses the radial extent and density of bird echoes on the Plan Position Indicator (PPI) scope of a surveillance radar. Density is assessed visually by comparison with a set of photographs representing the scale of the nine standard densities. Intensity 0 corresponds to no or very few bird echoes on the scope, and 8 indicates that the whole screen is densely covered with bird echoes (Fig. 1).

Patterns of hourly density of bird movements were obtained from radar films taken during the migration seasons of previous years (spring 1965 through 1968; fall 1965 through 1969). Maximum, minimum, and average hourly intensities were plotted for weekly intervals from April 21 to June 1 and from August 14 to October 15 (see Figs. 2 and 3 for examples).

Richardson and Gunn (1971) related the density of migration both to single weather

factors, measured at Cold Lake, and to synoptic weather patterns. The main correlation they found was with surface wind direction: density was higher with tail wind. Considering only nights with tail winds, no other weather factor investigated had a statistically significant effect (Richardson, 1970).

Upper air winds and precipitation were not considered by Richardson and Gunn (*op. cit.*). During preliminary study of the September 1966 data for Cold Lake, I found that winds between W and N at altitudes of 900 metres (3000 feet) and 1515 metres (5000 feet) above ground level (agl), tended to be associated with heavy SE movements. These data also showed that large volumes of migration occurred on nights that were either calm at ground level or had surface winds between W and N. On all occasions when the intensity was 6 to 8 the mean direction of migration was between E and S. Rain is considered an unfavourable factor by Bagg *et al.* (1950), Lack (1960), Drury and Keith (1962), Richardson (1966), and Nisbet and Drury (1968).

Lack (*op. cit.*) suggested that, since the causal links in migratory behaviour are still to be analysed, one should not use the terms "stimulus" and "deterrent" when describing the influence of weather factors on migration, but instead use "associated with" (or "favourable to") and "unfavourable to". I use Lack's terminology.

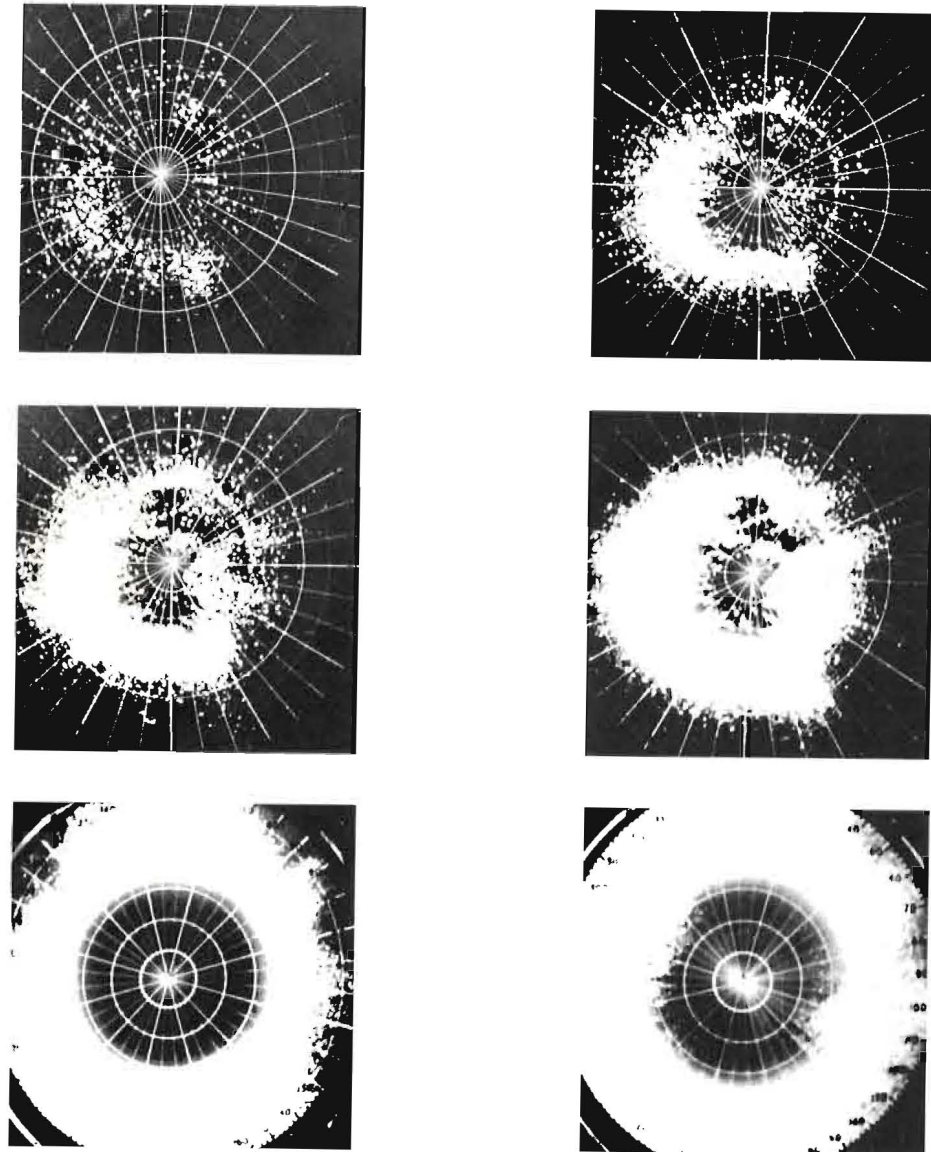
The four factors of the local weather used for the migration forecast system are given in Table 1.

The limits of these classes are not strict, and subjective decisions were often necessary. For example, a WSW surface wind in autumn was considered slightly favourable, especially if the winds aloft were northwesterly. Also, strong head winds (16 km/hour or more) were considered more unfavourable than light ones (6–10 km/hour).

Figure 1

Density scale used to measure bird movements at Cold Lake, Alberta. Reading from left to right and top to bottom, density levels 2, 3, 4, 5, 7, and 8 are shown. Range rings are 18.5 km (10 n. mi.) apart. There are no bird echoes near the centre of the display because of performance characteristics of the radar

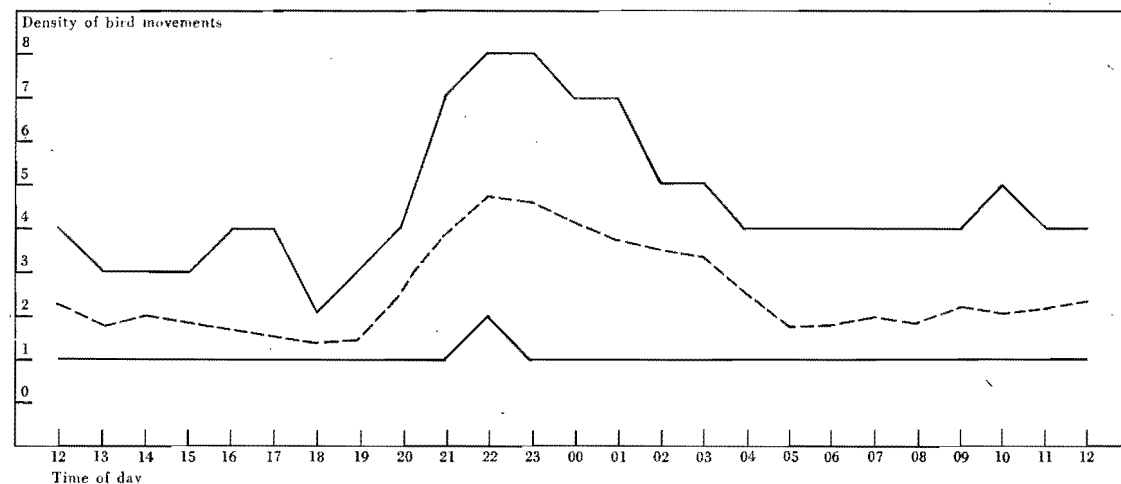
Figure 1



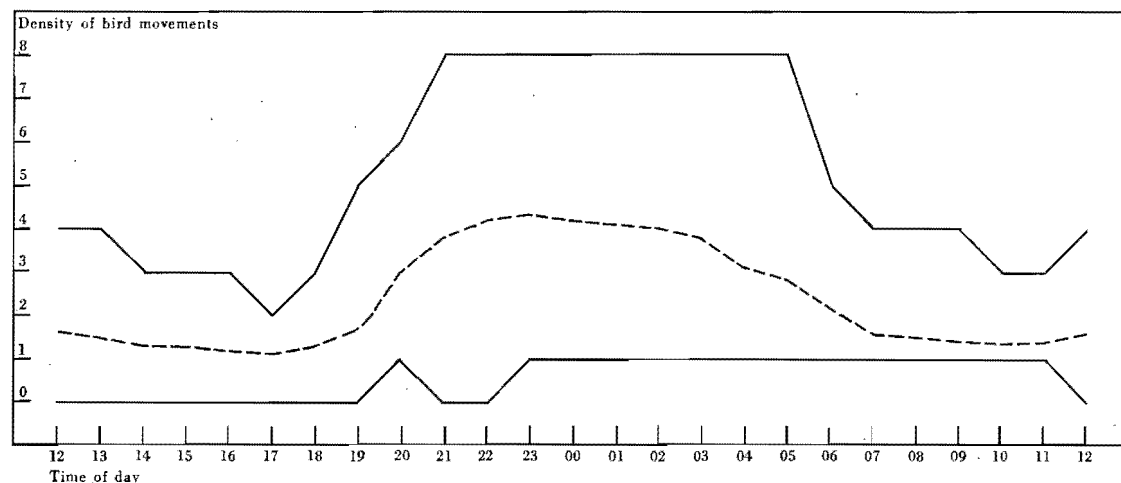
**Figure 2**  
Density pattern of bird movements May 5-11, 1965-68, at Cold Lake, Alberta. Broken line: average. Solid lines: maximum and minimum recorded for those years

**Figure 3**  
Density pattern of bird movements September 4-10, 1964-69, at Cold Lake, Alberta. Broken line: average. Solid lines: maximum and minimum recorded for those years

**Figure 2**



**Figure 3**



**Table 1**  
Weather factors used to forecast the density of migration over Cold Lake, Alberta

	Favourable		Neutral	Unfavourable	
	Spring	Fall	Spring & fall	Spring	Fall
Surface wind	S-E or calm (0-5 km/h)	N-W or calm (0-5 km/h)	S-W or N-E	N-W	S-E
Wind at 900 m (3000 ft) agl	S-E or calm (0-5 km/h)	N-W or calm (0-5 km/h)	S-W or N-E	N-W	S-E
Wind at 1515 m (5000 ft) agl	S-E or calm (0-5 km/h)	N-W or calm (0-5 km/h)	S-W or N-E	N-W	S-E
Precipitation	None	None	A few widely scattered showers	Extensive fields	Extensive fields

The following guidelines were used to forecast migration density:

- (1) If all weather factors are neutral, the migration will be of average intensity. If most factors are favourable, the migration density will be above average, with maximum intensities occurring if all factors are favourable. Minimum intensities will occur with all factors unfavourable, but extensive prolonged precipitation alone will also suppress migration completely even if all wind factors are favourable.
- (2) If one wind factor is unfavourable but another favourable, they will neutralize each other.
- (3) If all or most weather factors have been unfavourable for three consecutive nights, their inhibiting effect will decrease and the birds will start to fly under unfavourable conditions in numbers greater than usual.
- (4) When, late in the season (end of May and beginning of June in spring and October in fall), all or most weather factors have been favourable for two or three nights, the number of migrating birds will decrease even though favourable conditions continue.
- (5) Forecasts are made so as to achieve the greatest "accuracy"; forecasts were considered "accurate" if they differed not more than plus or minus one scale unit from the actual density. As intensities 0 and 8 are rarely recorded, they should not be predicted. Instead, intensities 1 and 7 are to be forecast.

Weather forecasts were provided on special forms by the Base Meteorological Office.

Daily forecasts were made of the density of the night migration (1900 through 0500 hours) for spring (April 23-24 through May 27-28, 1970) and fall (August 15-16 through October 14-15, 1970). The forecasts were made at about 1530 hours, using the 1500 hours weather forecast. At 1600 hours, the migration forecasts were presented at the pilots' briefing for night flying.

Films were taken of a PPI scope of a surveillance radar of 42 Radar Squadron near Cold Lake to verify the forecasts. The film technique was described by Solman (1969) and the radar by Richardson and Gunn (1971).

All migration forecasts were made by Cpl. P. P. Desfosses, a meteorological technician who had obtained considerable experience in analysing radar film during several previous years and in forecasting migration in the fall of 1969. Before making a forecast, he studied the radar film for the previous night.

#### Determining the accuracy of the migration forecasts

Forecast densities of migration were checked against actual densities obtained from the radar films. As the forecaster also assessed the radar films the possibility of bias had to be considered. Therefore, after the forecast period, all films were reassessed by Desfosses. The second assessments,

used for this report, differed very little from the first estimates. I assume that memory bias was negligible at the time of reassessment.

The film record of radar data was incomplete (see discussion, practical problems): for spring there was available a total of 270 hours (70 per cent) out of a potential 385 hours (35 nights each with 11 hours), and for autumn a total of 340 hours (52 per cent) out of 660 hours (60 nights).

When assessing radar film it was sometimes difficult to determine the exact density for intermediate situations. Therefore all predicted hourly intensities differing not more than one unit from the actual density were considered as accurate, and I defined the overall accuracy of the forecasts as the number of hours with accurate forecasts, expressed as a percentage of the total number of hours. Predicted densities that differed by three or more units from the actual value were deemed "large errors".

#### Determining the accuracy of the weather forecasts

The accuracy of the weather forecasts obviously affects the accuracy of the migration forecasts. The weather forecasts were usually not detailed enough to determine their accuracy hour by hour, so accuracy was judged for whole nights.

A weather forecast was classed as inaccurate if: (1) The actual wind direction or speed at ground level, 900 metres agl, or 1515 metres agl was clearly in another category of favourableness than forecast during most of the period for which radar data were available, or

(2) heavy precipitation occurred in extensive areas during most of the period for which radar data were available, while occasional light or no precipitation had been forecast and vice versa.

Other weather forecasts were considered accurate.

The accuracy of the weather forecasts was determined from the local weather reports, weather maps for the surface and 850 millibar level and, whenever available, pilot balloons. All weather data were provided by the Meteorological Office of CFB Cold Lake. A meteorologist helped analyse complicated weather situations.

## Results

### Spring 1970

There were two nights with inaccurate weather forecasts (a total of 17 hours of radar data). The results obtained for nights with accurate weather forecast (a total of 253 hours) are given in Table 2. I used the Wilcoxon's matched-pairs signed-ranks test (Siegel, 1956) to test the differences between the forecast and actual densities. Because the hourly densities for one night were not independent, I calculated for each night the difference between the sums of the forecast and of the actual densities and applied the test on those differences. For nights with less than 11 hours of radar data, the difference between the two sums was multiplied by 11/ $n$ , where  $n$  is the number of hours with radar data. The test showed no significant difference between actual and forecast densities ( $P=0.61$ ,  $N=25$ ).

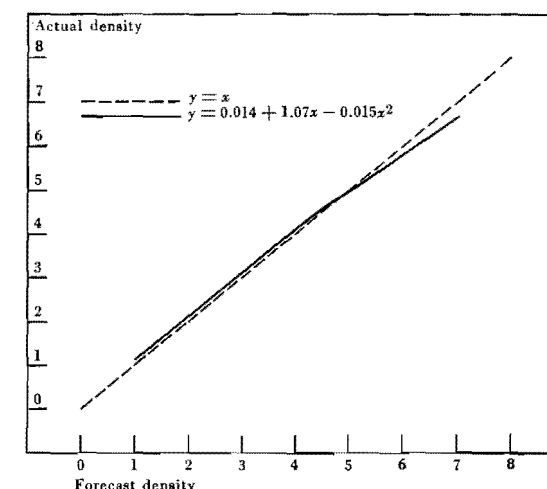
Second-order regression analysis (Snedecor and Cochran, 1967) showed very good agreement between forecast and actual hourly densities, and a slight tendency to underestimate low and overestimate high densities (Fig. 4). These tendencies were not tested for significance because it was very unlikely that appropriate tests, if available at all, would provide meaningful results.

**Table 2**  
Distribution of actual and forecast migration densities for nights with accurate weather forecast, spring 1970, Cold Lake, Alberta

Actual density	Forecast density							
	0	1	2	3	4	5	6	7
0								
1		19	26	2				
2		4	26	11	2			
3			22	19	9			
4			2	19	23	4		
5			1	2	12	19	6	
6					1	4	5	3
7						1	6	5
8								

**Figure 4**  
Second-order regression analysis of forecast and actual hourly densities of migration, spring 1970

**Figure 4**



Score rates, calculated from Table 2, are given in Table 3. The percentage of forecasts that were exactly right was rather low (46 per cent), but the overall accuracy (as defined in the previous section) was 96 per cent (Table 3a). When considering only the 65 hours with actual densities of 5 or higher (Table 3b), the accuracy dropped from 96 per cent to 92 per cent. Conversely, nearly all predicted heavy migration materialized (Table 3c). A total of 53 hours with density 5 or higher was predicted, with an accuracy of 98 per cent. Most night flying at CFB Cold Lake is done in the early evening (Table 3d). Accuracy for that period was only slightly lower than for the whole night (95 vs. 96 per cent).

### Fall 1970

There were six nights with inaccurate weather forecast (a total of 62 hours of radar data). Results for the nights with accurate weather forecast (273 hours) are given in Table 4.

**Table 3**  
Score rates for the migration forecast system for nights with accurate weather forecast, spring 1970, Cold Lake, Alberta

	Number of hours	% of total hours
<i>a. All densities</i>	253	100
A-F* = 0	116	46
A-F = ±1	126	50
Total accurate forecasts†	242	96
A-F ≥ 3 or ≤ -3‡	1	0
<i>b. Actual densities of 5 or higher only</i>	65	100
A-F = 0	29	45
A-F = ±1	31	48
Total accurate forecasts	60	92
A-F ≥ 3 or ≤ -3	1	1
<i>c. Forecast densities of 5 or higher only</i>	53	100
A-F = 0	29	55
A-F = ±1	23	43
Total accurate forecasts	52	98
A-F ≥ 3 or ≤ -3	0	0
<i>d. All densities, 2000 through 2300 hours only</i>	95	100
A-F = 0	37	39
A-F = ±1	53	56
Total accurate forecasts	90	95
A-F ≥ 3 or ≤ -3	1	1

\*The difference between actual and forecast density.

†As defined in section "Determining the accuracy of the migration forecasts".

‡These differences were considered as "large errors".

The forecast and actual densities showed a statistically significant difference ( $P=0.0092$  for the hypothesis that the differences of the sums of actual and of forecast densities for 29 nights, each consisting of 11 hours, are 0; Wilcoxon's two-tailed matched-pairs signed-ranks test).

Agreement between forecast and actual densities was much weaker in fall (Fig. 5) than in spring. The tendencies to underestimate low and to overestimate high densities were more pronounced than in spring, but were not tested for significance.

**Table 4**  
Distribution of actual and forecast migration densities for nights with accurate weather forecast, fall 1970, Cold Lake, Alberta

Actual density	Forecast density							
	0	1	2	3	4	5	6	7
0								
1		1	4	1				
2			7	8				
3			9	11	12	1		
4		1	6	19	9	5	1	
5			1	17	30	27	16	5
6				16	19	23	8	
7				1	2	3	9	
8						1		

**Table 5**  
Score rates for the migration forecast system for nights with accurate weather forecast, fall 1970, Cold Lake, Alberta

	Number of hours	% of total hours
<i>a. All densities</i>	273	100
A-F* = 0	87	32
A-F = ±1	133	49
Total accurate forecasts†	220	81
A-F ≥ 3 or ≤ -3‡	3	1
<i>b. Actual densities of 5 or higher only</i>	178	100
A-F = 0	59	33
A-F = ±1	76	43
Total accurate forecasts	135	76
A-F ≥ 3 or ≤ -3	2	1
<i>c. Forecast densities of 5 or higher only</i>	120	100
A-F = 0	59	49
A-F = ±1	51	43
Total accurate forecasts	110	92
A-F ≥ 3 or ≤ -3	0	0
<i>d. All densities, 1900 through 2200 hours only</i>	111	100
A-F = 0	30	27
A-F = ±1	56	50
Total accurate forecasts	86	77
A-F ≥ 3 or ≤ -3	3	3

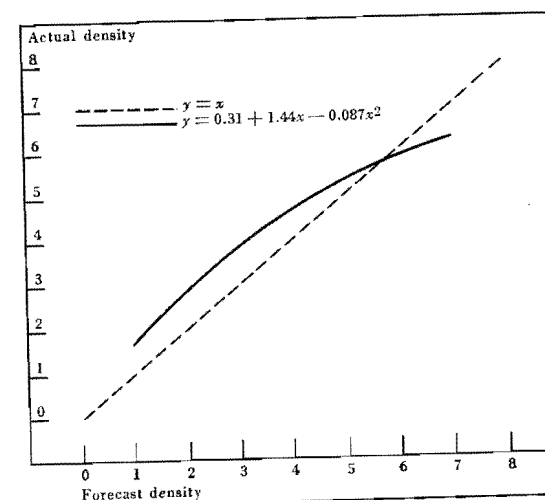
\*The difference between actual and forecast density.

†As defined in section "Determining the accuracy of the migration forecasts".

‡These differences were considered as "large errors".

**Figure 5**  
Second-order regression analysis of forecast and actual hourly densities of migration, fall 1970

**Figure 5**



**Table 6**  
Score rates for the migration forecast system for nights with inaccurate weather forecast, fall 1970, Cold Lake, Alberta

	Number of hours	% of total hours
<i>All densities</i>	62	100
A-F* = 0	13	21
A-F = ±1	25	40
Total accurate forecasts†	38	61
A-F ≥ 3 or ≤ -3‡	10	16

\*The difference between actual and forecast density.

†As defined in section "Determining the accuracy of the migration forecasts".

‡These differences were considered as "large errors".

Score rates, calculated from Table 4, are presented in Table 5. The accuracy of the forecasts was 81 per cent (compared to 96 per cent in spring). Considering only actual densities of 5 or higher (Table 5b), the accuracy dropped from 81 per cent to 76 per cent. Predictions of high densities (Table 5c) were 92 per cent accurate.

Accuracy for the early evening (Table 5d) was slightly below that for the whole night (77 vs. 81 per cent).

Score rates for the six nights with inaccurate weather forecast are given in Table 6. Compared to the results for nights with accurate weather forecasts, there is a decrease in accuracy from 81 to 61 per cent and an increase in large errors from 0 to 18 per cent.

### Weather factors and guidelines used

It is generally accepted that North American migrants fly the pressure patterns, i.e. with tail winds (for references and discussions see Nisbet and Drury, 1968 and Richardson and Gunn, 1971). Bruderer (1971), in contrast to earlier European authors, reported that European birds behave similarly.

In their study of the Cold Lake data, Richardson and Gunn (1971) considered seven weather factors: direction of surface wind, temperature relative to normal, temperature change from previous day, pressure trend, speed of surface wind, cloud extent, and humidity. The most important correlation was with tail wind and, analysing only data with following wind using the multiple discriminant analysis technique, Richardson (1970) stated "... once [surface] wind direction has been used to predict migration volume at Cold Lake, the use of other weather parameters does not seem to give a statistically improved predictive ability. Nevertheless, as already described, some correlation of intensity with individual weather parameters besides wind direction did exist [a positive correlation with low humidity for forward spring migration and none for forward fall migration], and hence consideration of these parameters may give a slightly improved prediction ability." To keep the system as simple as possible I did not use the correlation with humidity for spring.

Wind direction can change greatly with height. There can be a very favourable air flow aloft, with neutral or unfavourable winds at the surface (Preston, 1954; Hochbaum, 1955, p. 172; Blokpoel, 1970c, p. 344; Richardson, 1971, p. 690). The inclusion of upper air winds in the forecast system is therefore an attempt to take into account the general weather situation.

The effect of rain and snow on migration is not well known, as visual and radar observations

are both hard to make under such weather conditions. However, some authors (Bagg *et al.*, 1950; Lack, 1960; Drury and Keith, 1962; Richardson, 1966; Nisbet and Drury, 1968) have found rain suppresses migration and I have used their results. I assumed that falling snow has the same effect.

The forecast guidelines reflect the following concepts: high-density migration is likely during favourable weather following a period of unfavourable weather (Hassler, Graber, and Bellrose, 1963); after long delays birds are more eager to fly (e.g. Blokpoel, 1971); after long periods of favourable weather the number of birds physiologically ready to migrate decreases. I agree with Lowery and Newman (1966) that it is dangerous to predict ornithological results from weather alone.

### Shortcomings of the forecast system

The numerical relationships between the steps of the 0-8 density scale are unknown. The algebraic averaging of the densities to obtain the weekly density patterns is of dubious validity. Richardson (1970), using quartiles, found that the nightly median density in September peaked just under intensity 4, whereas our mean intensity reached a peak just over 4.

The correlations between density and weather established by Richardson and Gunn (1971) are only qualitative, leaving room for personal interpretation by the forecaster. As the 0-8 density scale values were ordinal rather than interval, those authors could not justifiably use the multivariate procedures employed by Lack (1963) and Nisbet and Drury (1968). The latter authors arrived at migration density equations that would be very suitable for use in a migration forecast system, but Richardson and Haight (1970) cautioned against the use of multiple regression procedures to correlate the

volume of migration and highly interdependent weather parameters.

Only the local weather was used. However, birds passing over Cold Lake around midnight probably started their migration earlier that evening more than 160 km away, and the weather at their starting point probably was important as well.

All bird species were lumped together. Richardson (1970), referring to his study of migrating starlings, pointed out that "it is easier to predict the migratory behaviour of a single species which has been studied separately from others than it is to predict the total migration volume of all the species which fly past Cold Lake."

**Comparison with results for previous years**  
Fryers' (1966) made the first experimental migration forecast at CFB Cold Lake. Using mainly the principle that migrants tend to fly the pressure patterns (Bagg *et al.*, 1950), he made forecasts for spring and fall 1966 covering both day-time and night-time migration. Considering all densities and both seasons (a total of 2068 hours), his accuracy was 77 per cent; for actual densities of 5 or more accuracy was 34 per cent, with large errors occurring 44 per cent of the time.

I used Richardson's preliminary results (pers. comm.) to forecast nocturnal migration in the fall of 1968 and 1969 (Blokpoel, 1970a, b). Accuracy was higher than in 1966. Most inaccurate migration forecasts could be attributed to inaccurate weather forecasts, incorrect use of the guidelines, or unusual situations. To check the migration forecast system, I later made "forecasts" based on reports of the actual weather. The accuracy of these carefully made migration "post predictions" was 86 per cent (all densities) and 79 per cent (actual densities of 5 or more only) for 1968, and 38 per cent (all densities)

and 75 per cent (densities 5 or more) for 1969. These figures show good agreement with the forecast results for fall 1970 (81 per cent for all densities, 75 per cent for densities 5 or more).

### Practical problems and operational usefulness

The problems of determining bird density from the scope of a surveillance radar were discussed by Richardson and Gunn (1971), Houghton (1971), and Richardson (1972). In brief, bird density as shown on the scope depends on the size, density, height, direction, and speed of the migrants, as well as on the radar capabilities, adjustments, and "aids" (e.g. Moving Target Indicator, Sensitivity Time Control, Fast Time Constant, Circular Polarization). Many radar data were lost because radar adjustments often made it impossible to assess the radar films.

Other radar data were lost because no films were taken during radar maintenance and classified military operations and because the films sometimes jammed in the cassettes.

Most night flying is done in the early part of the night when bird density may rise rapidly. It is easier to predict the peak density for a night than to foretell at what hour peak density will be reached.

For military reasons I have no exact data on the number of hours of night-time flying and the number of hours cancelled because of the migration forecast. However, I am told that on a few nights flying was cancelled mainly because of the migration forecast (such decisions are of course usually based on other factors as well). Although the pilots were initially rather skeptical about the migration forecasts, their interest increased appreciably after they suffered a few bird-strikes during nights with heavy migration (Blokpoel, 1970b). In 1970 the migration forecasts were well received.

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