WP 9.

ON THE PREDICTABILITY OF SPRING MIGRATION OF SNOW GEESE ACROSS SOUTHERN MANITOBA, CANADA*

by

H. Blokpoel and W.J. Richardson

INTRODUCTION

The eastern population of the Lesser Snow and Blue Goose, Anser c. caerulescens (snow geese), winters along the coast of the Gulf of Mexico. In spring they migrate in a north-northwesterly direction through the United States and into southern Canada, where their first main migration stop-over area is located in southern-most Manitoba along the Canada/USA border (Fig. 1).

When migrating from the plains in southern Manitoba to the coasts of James and Hudson bays, the snow geese fly in north-easterly directions, often in large flocks. A good proportion of this population (estimated at 2,000,000 birds in the spring; Kerbes, 1975) crosses the Terminal Control Area of Winnipeg International Airport, an area with a radius of 56 km (30 n mi) with the centre at the airport (Fig. 1).

In spring 1969, a flock of snow geese was struck by an airliner 22 km northeast of Winnipeg. The aircraft was seriously damaged. Following this accident, the Associate Committee on Bird Hazards to Aircraft of the National Research Council of Canada was asked (1) to detect and warn of this spring migration and (2) to develop techniques to predict it.

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The two standard surveillance radars used for Air Traffic Control at Winnipeg International Airport and at other major airports in Canada (the AASR-1 and ASR-5) were found to detect goose flocks very well (Blokpoel, 1974). Equipment to provide bird warnings in the operational ATC environment would have to be largely automatic and be able to express the bird hazard in terms of bird strike probabilities. The prototype of a radar-based system to automatically detect and warn of migrating bird flocks has been designed and tested by Hunt (1977).

First efforts to develop techniques for predicting the annual flights of the snow geese involved the determination of (1) the usual migration chronology, and (2) the influence of the weather on amount and timing of migration. The underlying idea was that once migration patterns and the way they were affected by weather were known, density of goose migration could be predicted using the weather forecast. The first prediction model was based on (1) a rough idea of the migration chronology, and (2) the results of simple, univariate analysis of weather during 23 major goose flights known to have occurred in the period 1953-1969. This qualitative model was tested and modified using migration data for 1970-72 (obtained from radar films taken from the display of the 23-cm AASR-1 radar at Winnipeg Airport) and weather records (Blokpoel and Gauthier, 1975a). That paper discussed the feasibility of operational migration forecasts and concluded, "In summary, it seems possible to predict major waves of spring snow goose migration over the Winnipeg Terminal Control Area with reasonable accuracy and such predictions might serve to alert pilots and air traffic controllers. It is, however, not likely that this method can be sufficiently refined to be fully satisfactory in real-time operations."

Despite these sobering concusions, the Canadian Wildlife Service, at the request of the Ministry of Transport, provided operational migration predictions at Winnipeg Airport in 1974 using the revised model and locally prepared weather forecasts (Blokpoel and Gauthier, 1975b). The results were disappointing and the main problems were (1) an overly simple prediction model; (2) errors and lack of pertinent details in the weather forecasts; and (3) lack of information on the changes in distribution and numbers of staging geese as the migration season progressed. Blokpoel and Gauthier (1975b) concluded that "An improved migration prediction model with greater accuracy would only warn or alert pilots and air traffic controllers in a general way" and recommended further research and development work on a "bird/radar" (as was eventually developed by Hunt, 1977). The authors also mentioned that if migration predictions were to be made again, the prediction model would have to be improved. At the end of spring 1974 good-quality radar data were available for 4 migration seasons. This volume of data seemed large enough for multivariate analysis, as recommended by Richardson (1974). Such an analysis was subsequently carried out (Blokpoel and Richardson, 1978).

In this paper we (1) summarize the main findings of those multivariate studies of the influence of weather on snow goose migration (for details see Blokpoel and Richardson, 1978), and (2) discuss those findings in relation to the feasibility of operational goose migration predictions for ATC operations at Winnipeg International Airport.

MULTIVARIATE RELATIONSHIPS BETWEEN WEATHER AND SNOW GOOSE MIGRATION

When examining the influence of weather, we considered 25 weather variables measured at Winnipeg at the hour of peak migration in each half-day interval (0300-1500 and 1500-0300). Migration usually occurred in the morning and/or evening, reflecting the preferred take-off times of the geese (early morning and early evening). We also considered 9 weather variables measured at Pilot Mound (about 145 km southwest of Winnipeg) 2 hours before the peak hour, because most geese that flew over Winnipeg during the peak hour were believed to have departed from staging areas near Pilot Mound about 2 hours earlier (Blokpoel, 1974). The snow geese generally flew in northeasterly directions, so the following and side components of the wind were NE-SW and SE-NW, respectively.

Because migration volume was expected to change with the progression of the migration season and possibly with the time of day, we also considered temporal variables. Date and $(\text{date})^2$ were considered to account for the expected tendency of migration volume to increase, level off and then decrease as the season progressed. Period of day (0300-1500 or 1500-0300) was considered to account for possible preferences of the geese relative to the time of day.

We also considered the cumulative amount of migration during the season to date to determine whether the volume of migration could be predicted more accurately if one took account of the number of migration "waves" (major flights) of geese that had already moved over the area. As mentioned earlier, details about all variables, their scales and transformations are presented in Blokpoel and Richardson (1978).

Factor analysis, a multivariate technique, was used to reduce the large number (34) of original weather variables to a more manageable number (8) of weather "factors". All 8 "factors" were readily interpretable: each was an index or measure of a basic characteristic of the weather. The values of the "factors" (considered as indices of various weather features) appeared likely to be useful as predictors of migration volume. The 8 weather "factors" and their simple relationships to migration volume are shown in Table 1.

The 8 weather "factors", the temporal variables and the "migration to date" variables were then used in multiple regression analysis of the migration volume during each half-day interval. Migration volume during each 12-hour period was expressed as the logarithm of the number of goose echoes observed during peak hour. The results of the regression analysis are shown in Table 2 (further details regarding the statistical procedures are in Blokpoel and Richardson (1978). As the equation in Table 2 shows, the most important predictors ($P < 0.0001$) were the following wind component "factor" and the temperature/humidity/pressure "factor". There also tended to be less migration on occasions with rain, cloudy skies and wind gusts than on fair and less windy occasions. In addition, the negative relationship to (number of preceding periods with ≥ 75 flocks in the peak hour)^2 indicated that migration volume tended to decline after several "waves" of snow geese had moved over Winnipeg. The relationship to (number of preceding periods)^2 was much more significant than that to (date)^2. This confirms the expectation that an indirect measure of the number of geese that have already moved over the Winnipeg area is a better predictor of migration volume than is date.

ACCURACY OF MIGRATION PREDICTIONS

The regression equation accounted for 67.8% of the day-to-day variance in migration volume (Table 2). Of this, 15.3% could be accounted for by consideration of temporal variables alone and 52.5% by subsequent consideration of weather "factors". A more direct indication of the forecasting ability of the regression equation may be obtained by inspection of scatter diagrams of "predicted" vs. actual migration volumes (Fig. 2). There was a strong correlation between observed and predicted migration volumes expressed on the logarithmic scale. The multiple correlation coefficient was 0.823. Of the 43 occasions when the predicted migration volume was 5 or less flocks in the peak hour, the actual migration was always less than 20 flocks and usually (35 of 43 occasions) zero; of the 31 occasions when the predicted volume was over 25 flocks, the actual volume was over 25 flocks on most (90%) occasions.

However, on a more detailed level, the predictions were not as accurate as one would wish. The predicting errors were sufficiently large that only the most extreme occasions could be distinguished with close to 100% reliability. For example, the predicted volume on the nine occasions with actual volumes of 100 or more flocks in the peak hour was usually (7 of 9 occasions) less than 60, although rarely (1 occasion) below 25. The reason for these large errors is the fact that migration volume had to be assessed on a logarithmic scale because it varied over a broad range and because of the technical requirements for the multivariate methods. Small errors in predictions of the logarithm of migration volume can represent large errors in the prediction of actual migration volume when volume is high (compare Figs. 1 and 2). The standard error of the estimates derived from the regression equation was 0.516 on the logarithmic scale (Table 2). This means that there is a 67% probability that the actual amount of migration would be in the range 0.61-6.6 flocks per hour if a volume of 2 flocks per hour were predicted, 6.1-66 if 20 were predicted, and 61-660 if 200 were predicted. The difference between 0.6 and 6.6 flocks per hour would be of little operational importance, but that between 61 and 660 would be of considerable importance. Although the accuracy of the predictions of snow goose migration compared favourably with results obtained in other studies (cf. Richardson, 1978, p. 233), the predictions were of "order of magnitude" accuracy only.

FEASIBILITY OF OPERATIONAL GOOSE MIGRATION PREDICTIONS

Blokpoel and Gauthier (1975a, b) discussed the feasibility of operational migration predictions in general, and of spring snow goose migration over southern Manitoba in particular. As mentioned earlier the main problems with the snow goose prediction system tested in 1974 at Winnipeg International Airport were (1) an overly simple prediction model, (2) errors and lack of pertinent details in the weather forecasts, and (3) lack of information on the changes in distribution and numbers of the geese as the migration season progressed.

The prediction of migration based on simultaneous consideration of numerous weather variables is at present not feasible because the number of cases available for analysis (97) is too small to develop an optimal prediction model. Migration predictions using weather "factors" are likely to give more reliable forecasts. Table 2 shows that the regression equation using weather "factors" and temporal and "migration to date" variables explained 67.8% of the day-to-day differences in amount of migration (52.5% being accounted for by the weather "factors", and 15.3% by the temporal and "migration to date" variables).

Although migration predictions using weather "factors" had a high degree of statistical significance, the probability of large errors was nonetheless high because of logarithmic scaling of snow goose migration volume.

Operational migration forecasts based on weather factors would add some problems to those mentioned above:

(1) Estimation of the value of each weather "factor" from observed or forecast values of the weather variables would involve a substantial amount of arithmetic and would hence require a small computer or a time-sharing computer terminal.

(2) Our analysis was based on records of the actual weather. Migration predictions would, in part, have to be based on weather forecasts, which are subject to error. Thus operational predictions would be less accurate than the above analysis suggests.

(3) The models developed here predict migration density during the peak hour of each 12-hour period. For operational purposes, some method of extrapolating those predictions to an hour-by-hour basis would be necessary.

(4) The present study confirmed the expectation that the number of birds ready to migrate with specific weather conditions is highly and negatively correlated with the numbers that have already flown overhead. The inclusion of (the number of preceding periods with ≥ 75 flocks in the peak hour)^2 in the regression equation contributed considerably to the predictability of migration volume. However, it

would be preferable to use a more refined measurement of "total migration to date" (e.g. counts of flocks detected by radar every hour) or, even better, to consider counts of geese remaining on the staging grounds. Consideration of either (or both) of these values would increase the accuracy of the prediction model, but would require considerable additional efforts to obtain the necessary data.

Because of their low accuracy and the difficulties mentioned above, migration predictions based on weather "factors" would be inadequate to serve as a useful indicator of the probability of a collision between an airliner and a flock of migrating geese; they would not be sufficiently accurate to warrant, when dense migration is predicted, such disruptive action as diversion of flights or delay of take-offs and landings. In contrast, specially designed or modified radars can be used to automatically monitor the number of flocks aloft and such numbers can be readily converted to bird strike probabilities (Blokpoel, 1976; Hunt, 1977). Although migration predictions might be useful in alerting Air Traffic Controllers and pilots in a general way, a real-time radar-based migration monitoring system appears necessary to cope effectively with the hazard caused by migrating snow geese at Winnipeg.

It does not directly follow from this conclusion that, in other circumstances, migration predictions are of little operational value. Their value may be strongly affected by the types and numbers of birds, by location, and by the type of aircraft and flight operations. In some military training programs, false "bird alarms" may be less disruptive and bird strikes may be more likely to cause serious damage or fatalities. In such cases, even an imprecise predicting capability may be useful. For example, at Canadian Forces Base Cold Lake in east-central Alberta, routine predictions of songbird migration are made each year during spring and fall (Blokpoel, 1973). In general, however, it should be recognized that statistically significant predicting capabilities are not necessarily of operational usefulness.

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Addresses of the authors: H. Blokpoel, Canadian Wildlife Service, 1725 Woodward Drive, Ottawa, Ontario, Canada, K1G 3Z7; W.J. Richardson, LGL Ltd., environmental research associates, 44 Eglinton Ave. W., Toronto, Ontario, Canada, M4R 1A1.

TABLE 1. Weather "factors" extracted from 34 weather variables and their simple relationships to migration volume.

Weather "factor"	Product-moment correlation	
	r	Significance level
Precipitation (Factor 1)	-0.315	0.01 > P > 0.001
Side wind component (Factor 2)	0.292	0.01 > P > 0.001
Wind speed (Factor 3)	-0.210	0.1 > P > 0.05
Following wind component Factor 4)	-0.605	P < 0.001
Temperature/Humidity/Pressure (Factor 5)	0.523	P < 0.001
Cloudiness (Factor 6)	-0.286	0.01 > P > 0.001
Gustiness (Factor 7)	-0.241	0.05 > P > 0.01
Pressure (Factor 8)	0.079	n.s.

TABLE 2. Multiple regression equation for migration volume based on stepwise analysis of weather "factors", temporal variables, and "migration volume to date" variables (N = 97)[a].

Predictor	Coefficient[b]	Standard Error	Significance Level
Day in May	0.118	0.080	n.s.
(Day in May)^2	-0.002	0.004	n.s.
Number of preceding periods with $\geq$75 flocks in the peak hour	0.103	0.087	n.s.
(Number of preceding periods with $\geq$75 flocks in the peak hour)^2	-0.030	0.010	$0.01 > P > 0.001$
Precipitation ("Factor" 1)	-0.193	0.060	$0.01 > P > 0.001$
Following wind component ("Factor" 4)	-0.283	0.063	$P < 0.0001$
Temp./Rel. Hum./Bar. Press. ("Factor" 5)	0.361	0.062	$P < 0.0001$
Cloudiness ("Factor" 6)	-0.148	0.064	$0.05 > P > 0.01$
Gustiness ("Factor" 7)	-0.180	0.062	$0.01 > P > 0.001$
Pressure ("Factor" 8)	0.107	0.055	$0.1 > P > 0.05$
Constant	0.189		
Multiple correlation (R)	0.823		
% variance explained (R^2 x 100)	67.8		
Standard error of transformed estimate	0.516		

[a]The top 4 predictors were included in the equation regardless of significance; other predictors were excluded from the equation (and are not presented) if $P > 0.1$.

[b]Migration volume (on the logarithmic scale) = a constant (0.189) + (Day in May) x 0.118 + (Day in May)^2 x -0.002 + ... + Pressure ("Factor" 8) x 0.107.

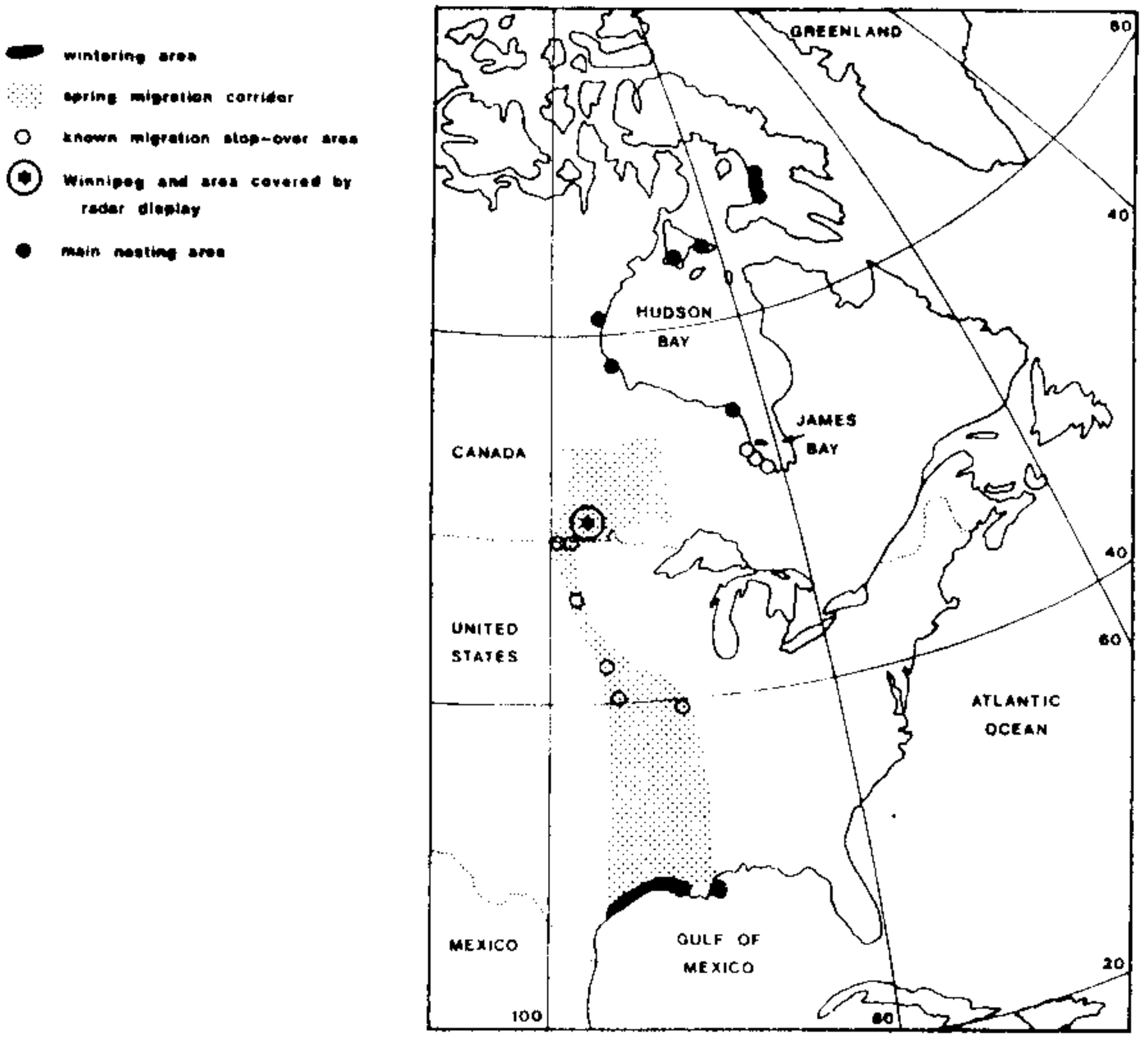

Figure 1. Range of the eastern population of snow geese (after Blokpoel, 1974 and Bellrose, 1978) and the area covered by the Winnipeg radar display used for the migration studies.

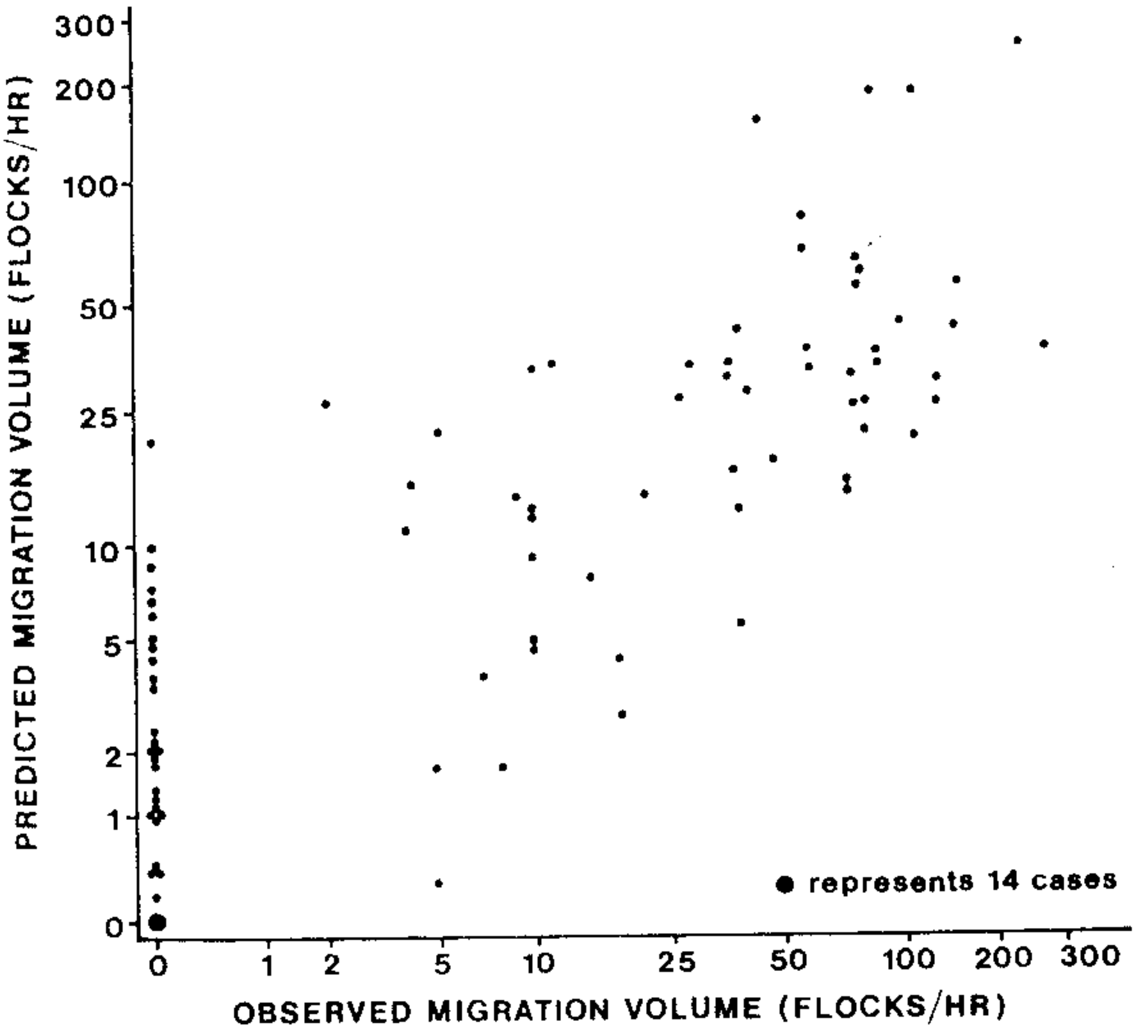

Figure 2. Migration volume predicted by the regression equation relative to observed migration volume, logarithmic scale (from Blokpoel and Richardson, 1978).

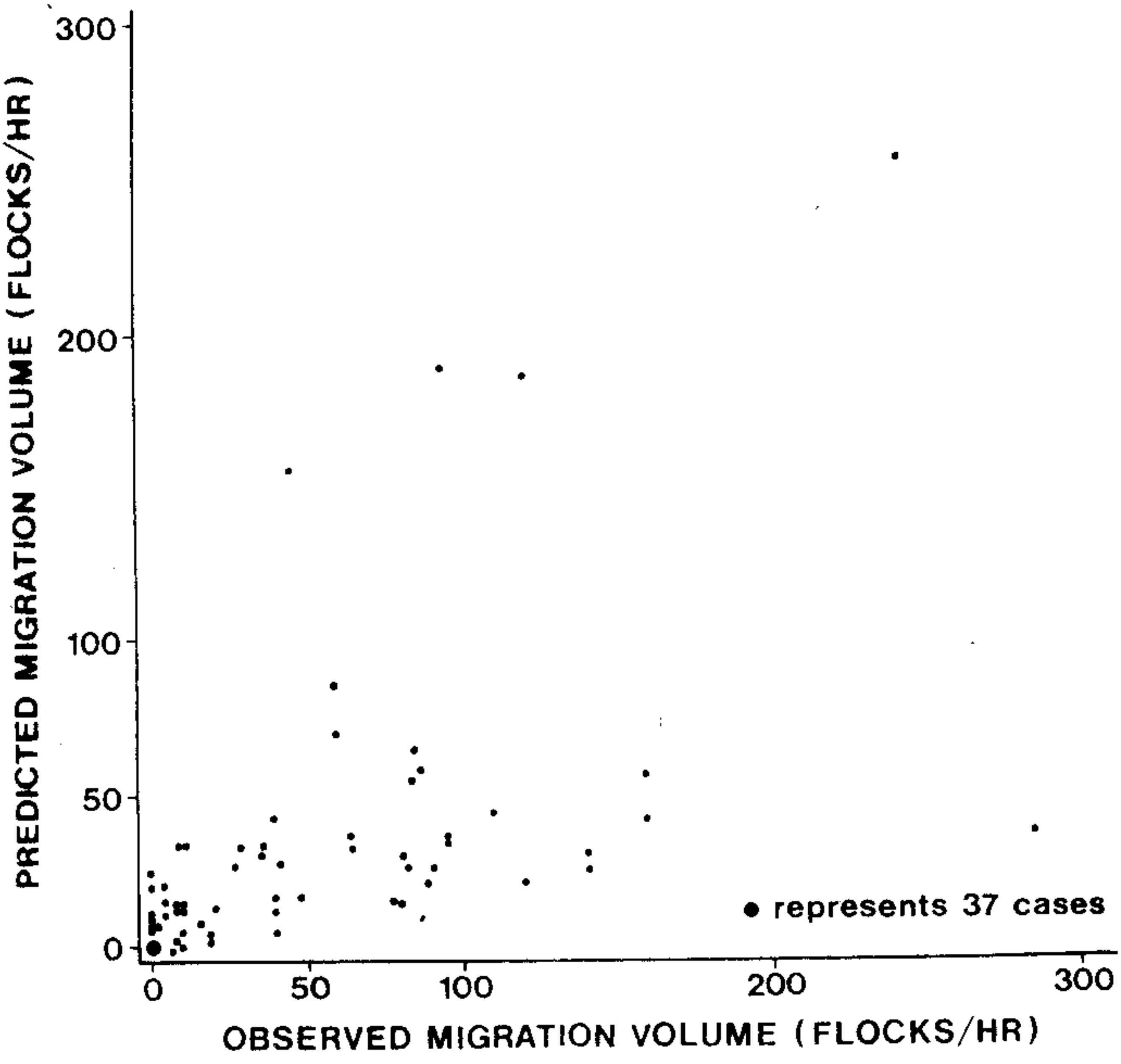

Figure 3. Migration volume predicted by the regression equation relative to observed migration volume, linear scale (from Blokpoel and Richardson, 1978).