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APPLICATION OF THE METHOD OF ITERATIVE MOVING AVERAGE FOR DETECTING BIRDS' MIGRATION WAVES

Abstract. The total number of birds migrating through an observation point at a given time depends both on endogenous programme of birds and current environmental conditions. For investigating bird migration it is important to be able to exclude the influence of environmental conditions as a random factor. In the present paper a new statistical method for smoothing out random fluctuations from curves depicting the migration dynamics of birds is presented. The method is applied to data about the spring migration of the long-tailed duck and the autumn migration of the common scoter.

Key words: migration dynamics, iterative moving average, long-tailed duck, common scoter.

Introduction

The migration dynamics (**MD**) of a given bird species describes the intensity of its passage through certain observation point(s) in a certain period. MD can be considered as the result of birds' endogenous programme under the permanent control of environmental conditions. As there exist both regular (alternation of seasons) and irregular phenomena (current weather) in the environment, the corresponding components in MD of birds can be suggested. Thus, any MD can be observed as involving the seasonal component (**SC**) describing the mean intensity of migration during a given period and the random component (**RC**) representing deviations from SC.

Distinguishing SC in MD means smoothing out RC from it. Different techniques have been used for this purpose but the methods used most frequently are the summing up of the census results of single days over longer periods of time, e.g., pentads (e.g., Jõgi, 1970a; Hjort, 1976) or decades (e.g., Hilden, 1976), and, sometimes, taking the average data of many years by dates (e.g., Hilden, 1976; Baumanis, 1990) before it. Smoothing out RC can be achieved also by means of an approximation with suitable functions. For example, Alerstam (1978) used the polynomes of the fifth and seventh degree for this purpose. Keskpaik used the cumulative curves of the migration flow to describe migration as a transition process. A special technique (Кескпайк, 1989) enabled him to divide MD into three phases. Zalakevicius (1990) attempted to approximate cumulative curves with a suitable function.

The described methods of smoothing leave several problems unsolved. Is the summing up of the total number of migrating birds by 5-

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or 10-day periods well founded or should we use periods of another duration? How does our choice depend on the amount of data? How can one be sure that the type and degree of the polynomes applied for approximation describe as much SC and as little RC as possible? Is the transition process under consideration unimodal or does it involve two (e.g., in different endogenous programmes for males and females) or more processes each with its own peak and it would therefore be better to describe them separately? These questions can arise in smoothing data with those methods. In the present paper a new method based on the iterative moving average is suggested for smoothing RC out of MD.

Definition of the Problem

Let us suppose that the migration of a certain bird species at a certain observation point (**OP**) and season is observed during the whole migration cycle (**MC**). This means that the observation period lasts from the beginning of the migration to its end without interruptions. Also, we suppose that optimum observation times, location of the observation point with respect to the migration route, and counting methods have been selected.

Since the expression of the whole duration of MC is too approximate due to difficulties in observing the first and the last migrating individual, it is better to use, instead, the period between quantiles. In this paper the quantiles of 2.5% and 97.5% have been used. So the period T^{95} between the quantiles involves 95% of the passage.

Observing a set of MC we get i observations of the number of birds N^{SR} passing OP at a given date t. We are interested in transforming N^{SR} into N^{S} so that RC occurring in N^{SR} would disappear with a great probability (95%), while SC would remain.

The following line of reasoning was used. Let us suppose that a single bird migrates over OP at a certain date t_i fixed by its endogenous programme. However, current signals from environmental conditions may cause its migration earlier (e.g., due to the social effect of the specimens whose endogenous programme is timed earlier, or the existence of a cyclone moving in the opposite direction with respect to the direction of migration) or later (unsuitable weather conditions in departure areas). So, if the bird does not pass OP at t_i, it will do it at t_{i-1} or t_{i+1}; if not, then at t_{i-2} or t_{i+2}, etc. As it is impossible to predict how many out of the total number of birds N_i^{SR} passing OP on a certain date t_i are "early," "late," or "on time," the only feasible way to solve the problem is to redivide the proportions of birds in both directions on the time axis. This is possible using the method of the moving average, which has proved successful in several closely related problems (Remm, 1987).

Method of Smoothing

The method of the moving average can lead to several different solutions depending on the averaging area, the step interval, and the model of calculating averaging weights. In our case, it is reasonable to use always the shortest possible average area, three days, which ensures the highest sensitivity of smoothing. Then the step interval has to be one day and this with the period of migration T^{95} will, in turn, determine also the number of steps j. Here different models of calculating averaging weights Q_{ij} provide quite similar results. The author found the quadratic model

$$Q_{ij}=1-(t_j-t_i)^2/2^2 \tag{1}$$

to be the most suitable. The weighted averages were calculated according to the formula

$$N_j^S=\frac{\sum_i (Q_{ij}N_i^{SR})}{\sum_i Q_{ij}}. \tag{2}$$

If used only once the variant of the moving average described transforms MD only to a small extent. However, if the same procedure is applied repeatedly, its "power" will steadily increase and we can continue until we get a unimodal curve. Actually, we are interested in finding out the optimum number of iterations n. It depends on two factors: (1) the number of MC (the more MC have been observed, the smaller n will be), and (2) the duration of MC (the longer the average duration of MC, the greater n will be).

Our problem can be formulated as follows: how many iterations does one need in any number of observation cycles of any duration to argue, at 95% significance level, that RC has been smoothed out of MD? To solve the problem a statistical experiment was carried out.

Statistical Experiment

Suppose that endogenous programmes in a certain set of birds (e.g., adult males of the population) are very similar, causing the initiation of migration in a certain period of the year so that the departure times of each single bird are distributed normally with the mean date t and variance s^2. Then the theoretical dynamics of the migration flow $\bar{N}^S$ can be determined by the formula

$$\bar{N}^S \sim N(\bar{t}, s^2), \tag{3}$$

where s^2 can be expressed by means of T^{95}:

$$s^2=\left(\frac{T^{95}}{2\times 1.96}\right)^2. \tag{4}$$

Suppose that all values of the theoretical MD $\bar{N}_i^S$ are distorted by some random influences. To get a dynamics as similar as possible with the one obtained from field observations, random influences have to be exponential. Doing so, the theoretical dynamics of the migration $\bar{N}_i^{SR}$ can be calculated as

$$\bar{N}_i^{SR}=-\ln(Rnd)\bar{N}_i^S, \tag{5}$$

where Rnd is a random number between 0 and 1.

As we stated previously, the number of iterations in smoothing data with the moving average depends on two factors: (1) the number of observed MC I and (2) the duration of MC T^{95}. Proceeding from this, theoretical data combinations from four values of T^{95} and six values of I were simulated, each 100 times, i.e., 24×100 theoretical MC.

Further, the method of the iterative moving average was applied for all MC. As it is known that the curve based on the data obtained from formulas (3), (4), and (5)must have only one peak, it is reasonable to smooth the data until they yield only one peak. As a result, one obtains 24×100 values of n and, using negative binomial or binomial distributions, the corresponding theoretical values of n at 95% significance level n^{95}, were estimated by all 24 distribution curves.

Theoretical values of the optimum number of iterations at 95% significance level n^{95} relative to the number of observed MC I and the duration of MC T^{95} obtained from the statistical experiment

T^{95}	I					
	1	2	4	8	16	32
10	4.65	3.40	2.30	1.54	1.00	0.96
20	14.11	10.24	7.19	5.29	3.57	2.77
40	44.12	32.20	23.39	14.35	12.04	8.15
80	135.28	110.30	68.76	65.00	50.00	25.46

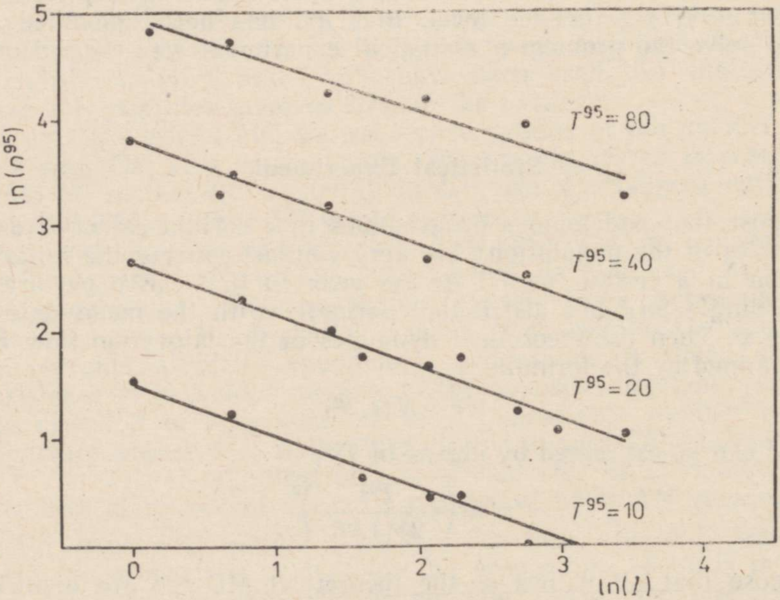

Fig. 1. Theoretical values of the optimum number of iterations at 95% significance level n^{95} (dots) relative to the number of observed MC I in four different durations of MC T^{95}. Logarithmic values of n^{95} and I have been used. Straight lines have been fitted by least squares.

If the results (Table) are transformed by taking a natural logarithm from both n^{95} and I, then at constant T^{95} a linear relationship seems to occur between $\ln(n^{95})$ and $\ln(I)$ (Fig. 1). The straight lines obtained by means of approximating the data at four different values of T^{95} with the method of least squares have approximately the same slope (mean —0.48) with an almost equal distance between them (mean 1.15).

Considering also that the line corresponding to $T^{95}=10$ intersects the y-axis at the point y=1.50, n^{95} can be calculated as

$$\ln(n^{95}) = -0.48 \ln(I) + 1.5 + 1.15 \log_2 \frac{T^{95}}{10}, \qquad (6)$$

which can be approximated as

$$n^{95} = \left[\frac{T^{95^{\frac{5}{3}}}}{10\sqrt{I}} + 1 \right]. \qquad (7)$$

Examples

1. The spring migration of the long-tailed duck (*Clangula hyemalis*)

The field work was carried out in 1984—1990, 1—31 May, each year except 1985 at the Puhtu Ornithological Station at the Suurväin Strait on the western coast of Estonia. Both visual (Veroman and Jõgi, 1961; Jõgi, 1970b; Адер and Кескпайк, in press) and simultaneous visual and radar studies (Jakoby, 1983) have shown that it is the best place for observing the departure of arctic ducks from the staging place in the Gulf of Riga to the breeding areas.

Using formula (7) the value of $n^{95}=6$ can be calculated considering that $I=7$ and $T^{95}=19$. For calculating the latter one has to make sure that the data of all the years taken together are sorted by dates. The result obtained after smoothing with the moving average with six iterations (Fig. 2) shows that the spring migration of the long-tailed duck can be regarded unimodal. The smoothed curve seems very close to that of the normal distribution, except a small hump on its left side. It is also possible to find a reasonable explanation of the formation of the hump. Here mainly two methods can be used: (1) analysis of the data of different years and different combinations of years separately and comparison of the results, or (2) shift of the initial data on the time axis to get a better fit of different years.

Considering that the spring passage of the long-tailed duck is a short-term process, the initiation and course of which is strongly affected by the lingering of winter conditions (especially ice cover) in their starting areas (Адер and Кескпайк, in press), the second method seems to be suitable in our example. Here a certain quantile (in this example the median) of each MD is supposed to correlate with the phenological phase of the corresponding year; further, MD has to be analysed relative to the quantile. This approach ensures a better fit of the MD of different years and more exact smoothed curve. Fig. 3 shows that the curve has no hump anymore and that it has also lost its normality: the migration wave is more abrupt at its beginning. In the *B*-part of the figure the same curve is compared with seven curves each obtained after smoothing the data of one year separately. The results are similar: only one curve has two very closely situated peaks. It shows that even one observation cycle can give quite exact results.

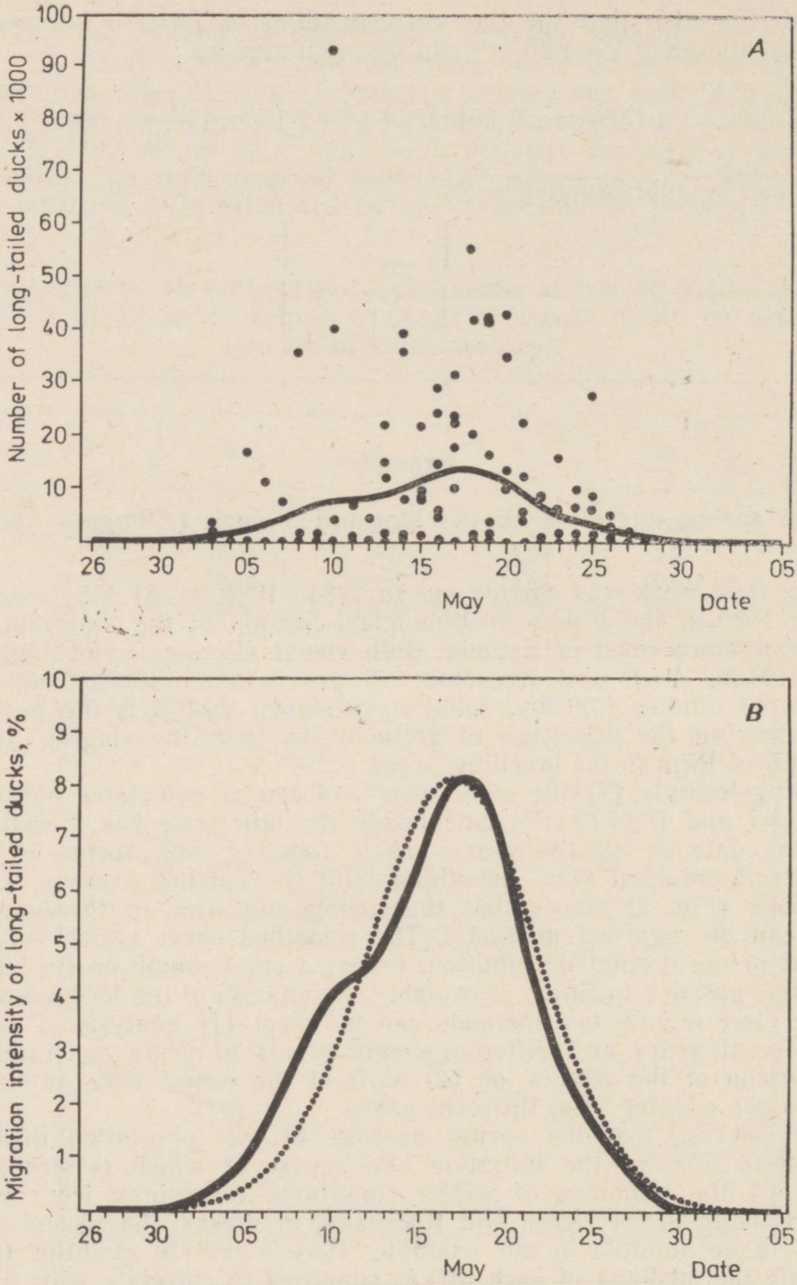

Fig. 2. The spring migration of the long-tailed duck (*Clangula hyemalis*) at Puhtu, West Estonia, during a 7-year period. *A*: The total number of birds observed per day (dots) and the corresponding curve obtained by smoothing with the iterative moving average. *B*: the same smoothed curve as in *A* (solid line) and the corresponding normal distribution (dotted line).

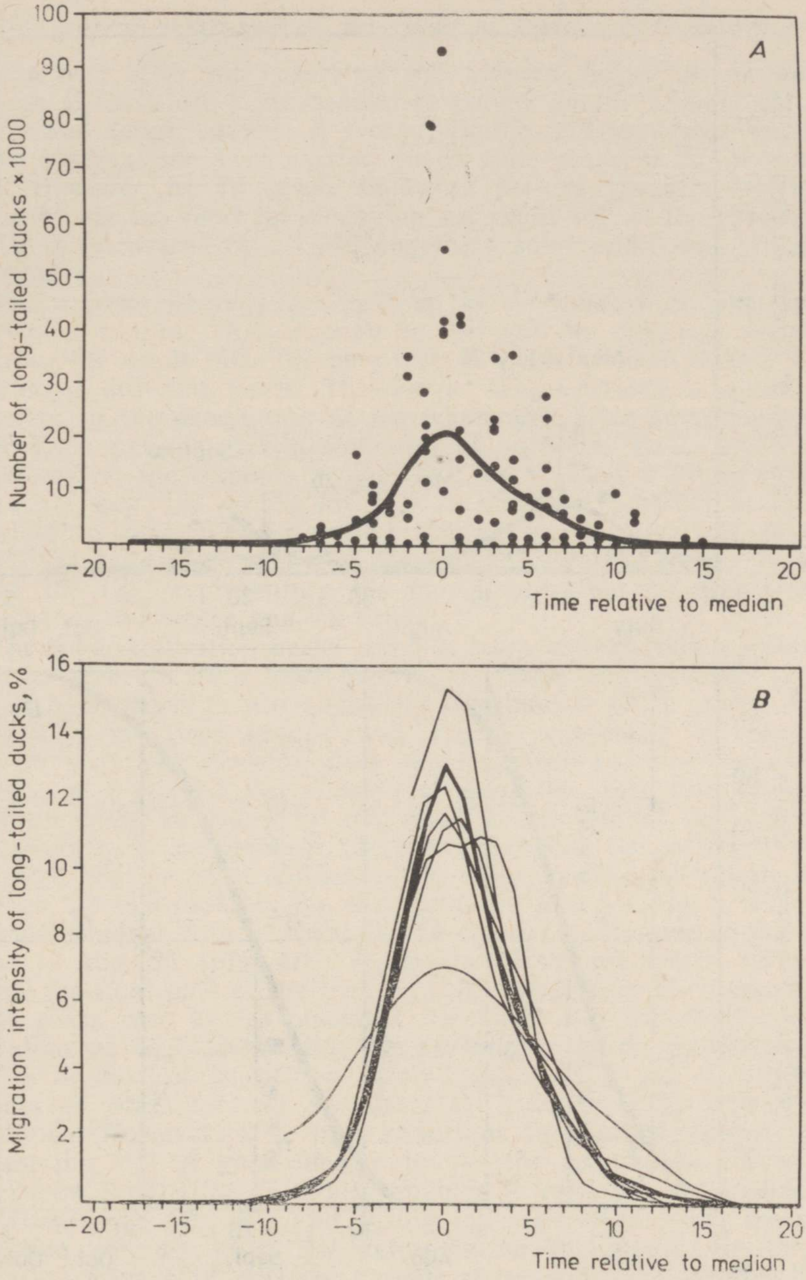

Fig. 3. The same data as in Fig. 2, with the yearly migration curves shifted so that their medians coincide. *A*: The total number of birds per day (dots) and the corresponding smoothed curve. *B*: The resultant curve (thick line) compared with seven curves each obtained by smoothing the data of one year separately.

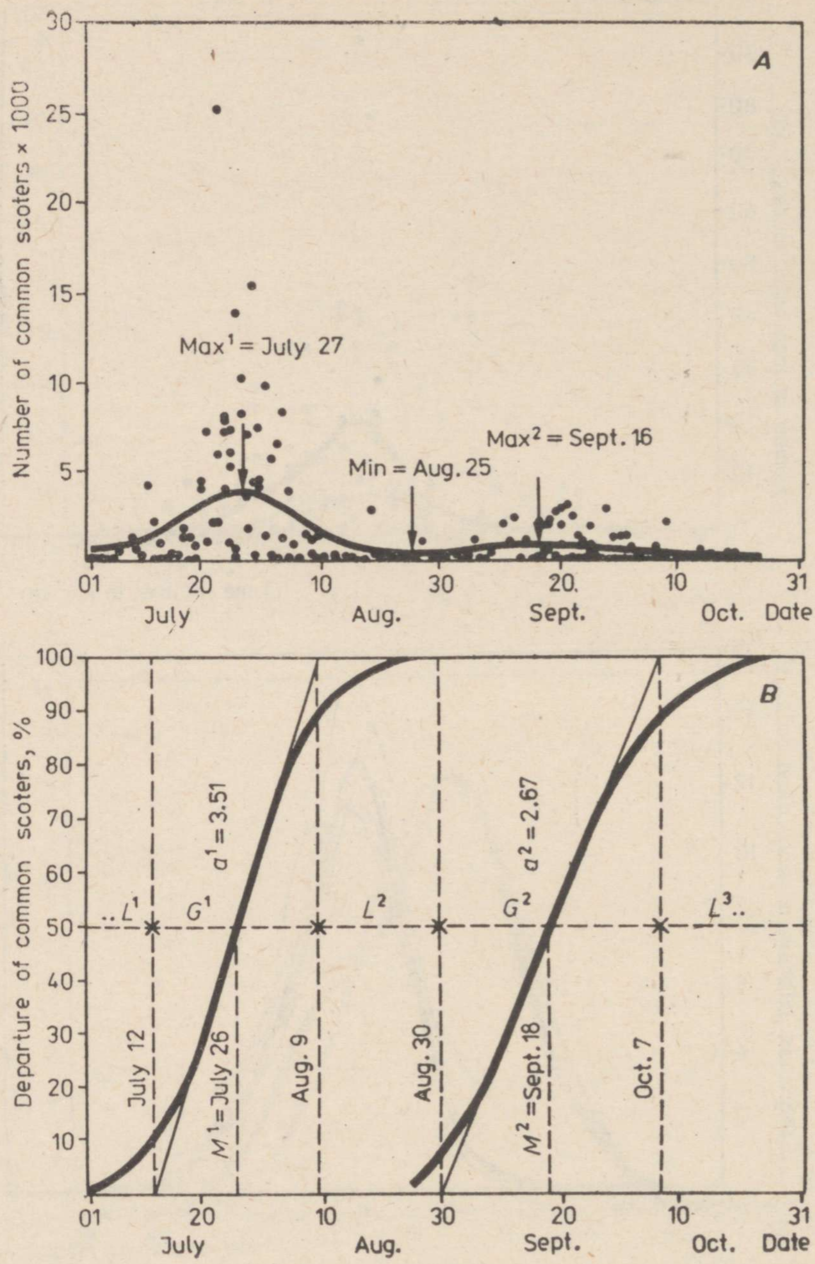

Fig. 4. The autumn migration of the common scoter (*Melanitta nigra*) at Viinistu, North Estonia. *A*: The total number of birds per day observed (dots) and the smoothed curve with two maxima. *B*: Time parameters of migration found from the cumulative curve. G^1 — generalized migration of males, G^2 — generalized migration of females and brood, $L^1 \ldots L^3$ — initial, intermediate, and final time lags. M^1 and M^2 — median days of migration; a^1 and a^2 — migration speeds (slopes of tangent).

2. The autumn migration of the common scoter (*Melanitta nigra*)

The best sites for observing the autumn migration of waterbirds through Estonia are some headlands on the southern coast of the Gulf of Finland (Jõgi, 1970b). A most suitable among them is Viinistu, where observations were carried out in nine years in the period 1960—1985. However, as all single fieldwork periods (usually lasting about a month) are too short for observing the whole MC of the common scoter (while it is covered by all MC together) some additional problems are to be solved.

The autumn passage can last up to six months or even longer in some bird species. Thus, it may be difficult to organize observations covering the whole MC. The only way is to use shorter periods distributed among different years. The longer these periods are, the smaller the error in the description of the whole MD after summing up single observation periods. While summing up all the data of 9-year observations on the common scoter, 2—5 or at least 2 observations were found per any day within MC, which makes it possible to take $I=2$. Considering that $T^{95}=82$ (calculated as usual), one has to perform smoothing by taking $n^{95}=110$. The resultant curve (Fig. 4) has two peaks, the first representing the moult migration of males and the second that of females and the brood.

These two migration peaks coincide more or less, which makes it difficult to separate them from each other. There exist several ways to do it. The best one is to use additional information (if it exists) to divide the initial data into groups and repeat smoothing in each group separately. In our example, data about the sex and age that, we think, serve as a basis for the division of migration into two groups, have not been collected regularly and therefore we cannot use this method. Another way is to intersect the curve between the adjacent peaks at the point that is least influenced by either peak. The minimum point between the two peaks is the very point we look for. So, in our example the most neutral date between the two migration waves of the common scoter is Aug. 25 (Fig. 4*B*). By means of the procedure, however, we cut off the final part of the first and the initial part of the second peak. These parts can be extrapolated in case the distribution of both migration waves is known, but this possibility will not be discussed here.

The method of smoothing treated gives us **a set of maxima and minima of MD** that can be useful for comparing different field observations. However, it is also important to apply additional methods to describe MD. A good idea is to use the cumulative curves of MD (Кескпайк, 1989) (Fig. 4), which enables to estimate **the median of the migration wave** (M^1, M^2) and (using the slope of tangent) **the speed of migration** (a^1, a^2) in it. By extrapolating this speed to the whole migration wave (Fig. 4*B*) **the periods of generalized migration** (G^1, G^2) situated between **the periods of time lags** ($L^1 \ldots L^3$) can be calculated.

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