The Gene Pool of the Belgorod Oblast Population: Malecot's Isolation-by-Distance Parameters

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Abstract—The mean distance between birthplaces of spouses (σ, σ'), the proportion of medium migrations (k), and the effective migration pressure (M_e) have considerably increased, and the linear systematic pressure coefficient (b) has decreased in the human population of the Central Chernozem region during the past 50 years. However, the local inbreeding level (a), which is determined by both an increase in the migration intensity and a decrease in the effective population size (N_e), has remained practically unchanged. A change in the regional administrative structure has affected the genetic structure of populations. In the 1950s, raions (administrative districts) of Kursk and Voronezh oblasts (regions) were similar with respect differentiation parameters, whereas the oblasts considerably differed from each other. At present, some Malecot's isolation-by-distance parameters for the populations of the districts that were included to Belgorod oblast in 1954 are lower and similar to those for the districts that remain in Kursk and Voronezh oblasts.

MINTRODUCTION

Marriage migration parameters, including those of Malecot's isolation-by-distance model, are important characteristics of population structure. Malecot's isolation-by-distance model adequately describes the structure of the modern population, and the local inbreeding level (a) corresponds to the population subdivision parameter (F_{st}) calculated from the data on surnames. The possibilities of estimating both interpopulation and intrapopulation genetic relationship and studying a considerable number of subpopulations are important advantages of the model [1, 2].

The approach to the estimation of inbreeding based on Malecot's isolation-by-distance model is widely used in studies on the genetic structure of various populations, including that of middle Dalmatia in the former Yugoslavia [3] and modern island populations of Bar [4] and other places [5].

Malecot's isolation-by-distance model was used to study the populations of Moscow [6], the Non-Chernozem region of Russia [7], Kursk oblast [8], Marii El [2, 9], Adygea [10], Ukraine [11], Chuvashia [12], etc.

In this study, we used Malecot's isolation-by-distance model to analyze the changes in the marriage migration characteristics of populations of southern central Russia during the past 50 years.

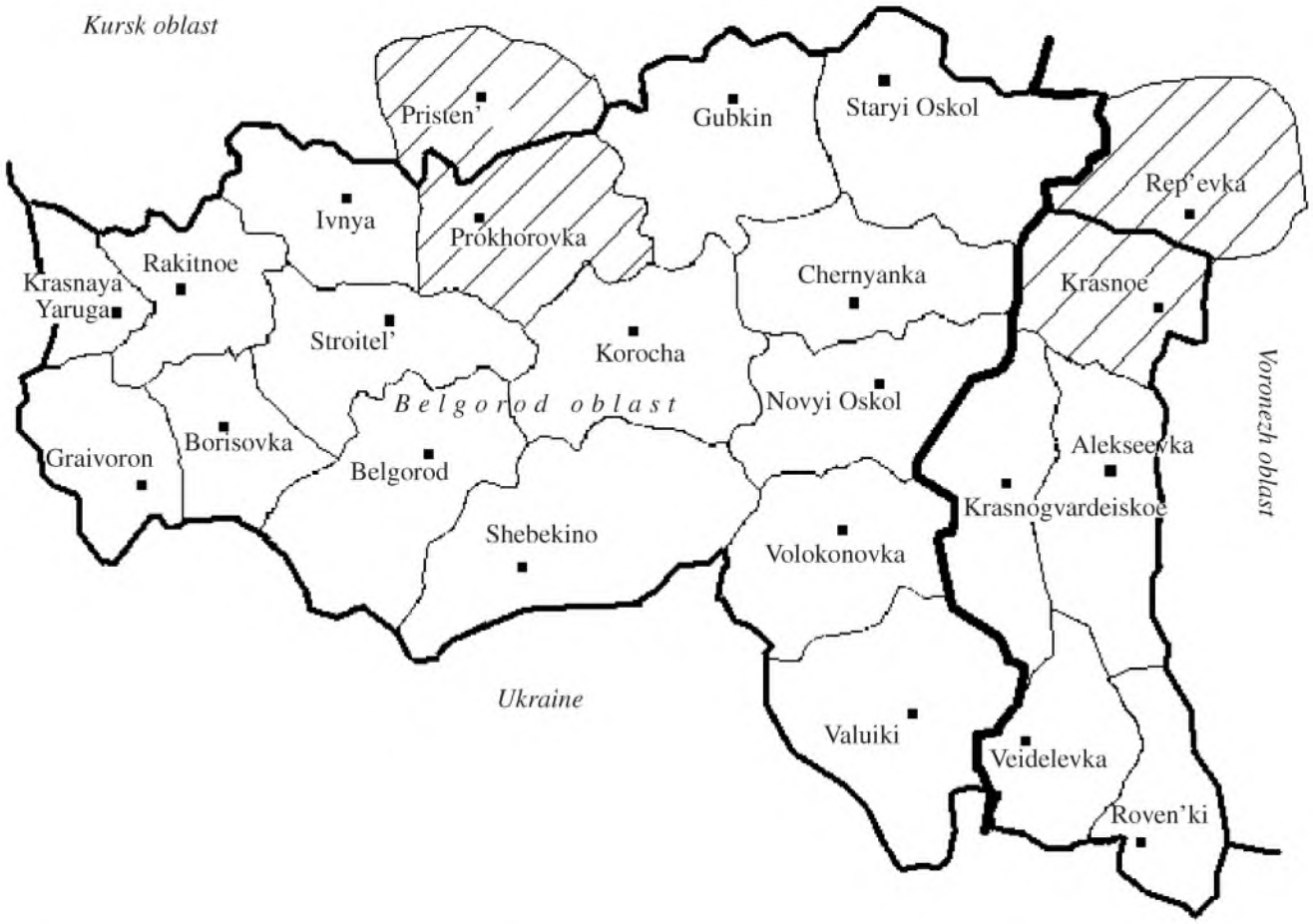
MATERIALS AND METHODS

Populations

Since Belgorod oblast was established as an administrative region as recently as 1954, we studied the population genetic mechanisms of the formation of the new regional population by analyzing the changes in population parameters, with the use of Malecot's isolation-by-distance model, during two periods: 1947–1953 (before Belgorod oblast was established) and 1987–2001. We studied the populations of two pairs of neighboring districts: (1) Pristen' raion (an administrative district of Kursk oblast) and Prokhorovka raion (a district of Kursk oblast before 1954 and a district of Belgorod oblast afterwards); (2) Rep'evka raion (a district of Voronezh oblast) and Krasnoe raion (a district of Voronezh oblast before 1954 and a district of Belgorod oblast afterwards) (figure).

Prokhorovka raion is located in northern Belgorod oblast and borders on Pristen' raion of Kursk oblast. The district population is 27800 people. The district comprises 19 rural municipalities. Pristen' raion of Kursk oblast comprises 18 rural municipalities with a total population of 10100 people.

Krasnoe raion is located in northeastern Belgorod oblast and borders on Rep'evka raion of Voronezh oblast. The population of Krasnoe raion is 15500 people. The district comprises ten rural municipalities. The population of Rep'evka raion of Voronezh oblast, comprising 11 rural municipalities, is 10100 people. Note that the administrative centers of all the districts studied are, as a rule, the villages (rather than towns) that have



The map of the rural districts of Belgorod oblast. The analyzed districts are hatched (Prokhorovka and Krasnoe raions of Belgorod oblast, Pristen' raion of Kirsk oblast, and Rep'evka raion of Voronezh oblast). The thick line shows the border between Kursk and Voronezh oblast before 1954, the year when Belgorod oblast was established.

large populations than other villages in the respective districts. This administrative organization of rural districts is typical of the Central Chernozem region (e.g., the administrative centers of 29 out of 49 districts of Kursk and Belgorod oblasts are villages, and only 20 district centers are towns or cities).

We selected for analysis five "model" rural municipalities in each district (except for Rep'evka raion, where four municipalities were studied). More than 95% of residents of these districts were Russian.

Population Genetic Study

The population marriage migration structure and its changes during the past 50 years were studied using Malecot's isolation-by-distance model. The original data were taken from 5584 marriage records from the archives of the regional registry offices of Belgorod, Kursk, and Voronezh oblasts (3307, 1342, and 935 records, respectively), a total of 2920 records on marriages contracted in 1949–1953 and 2664 records for the period 1987–2001. We copied the data on the spouses' birthplaces. Malecot's isolation-by-distance parameters were calculated by the standard method described elsewhere [5, 7, 8, 13, 14].

The changes in the population genetic structure in the Central Chernozem region during the past 50 years were studied at the levels of both of rural municipality (an elementary population in the 1950s) and district (an elementary population in the 1990s, as we demonstrated in the previous study [15]).

RESULTS AND DISCUSSION

We estimated the parameters of isolation by distance at the level of elementary populations (rural municipalities) of four Central Chernozem districts in the 1950s and their changes during the lifespan of two generations (until the 1990s). The estimated parameters of isolation by distance for 19 analyzed municipalities of four districts in the 1950s and 1990s were used to calculate the mean Malecot's parameters at the municipality level (Tables 1, 2). In addition, since an elementary population began to correspond to a district one in the

Table 1. Changes in Malecot's isolation-by-distance parameters in Prokhorovka and Pristen' raions in the period between the 1950s and 1990s

Parameter	Prokhorovka raion						Pristen' raion					
	Values averaged over rural municipalities			Values for the total district population			Values averaged over rural municipalities			Values for the total district population		
	1950s	1990s	Change (1950s/1990s)	1950s	1990s	Change (1950s/1990s)	1950s	1990s	Change (1950s/1990s)	1950s	1990s	Change (1950s/1990s)
σ	13.66	48.69	*+3.56*	23.84	51.99	*+2.18*	9.92	83.49	*+8.42*	13.89	87.60	*+6.31*
σ'	2.25	29.38	*+13.06*	4.82	32.25	*+6.69*	4.19	57.70	*+13.77*	3.22	57.70	*+17.92*
m	0.010	0.013	*+1.30*	0.009	0.009	*1.00*	0.007	0.022	*+3.14*	0.003	0.027	*+9.00*
k	0.089	0.394	*+4.43*	0.114	0.369	*+3.24*	0.171	0.289	*+1.69*	0.178	0.271	*+1.52*
M_e	0.042	0.098	*+2.33*	0.046	0.080	*+1.74*	0.045	0.112	*+2.49*	0.033	0.124	*+3.76*
N_e	1003	487	*–2.06*	17694	10859	*–1.6*	840	306	*–2.75*	14031	7123	*–1.97*
a	0.0073	0.0059	*–1.24*	0.00031	0.00029	*–1.07*	0.0091	0.0094	*+1.03*	0.00054	0.00028	*–1.93*
b	0.1463	0.0179	*–8.17*	0.0628	0.0124	*–5.06*	0.1274	0.0100	*–12.74*	0.080	0.0086	*–9.30*

Note: Here and in Table 2, σ, root mean square distance between spouses' birthplaces with long migrations taken into account; σ', root mean square distance between spouses' birthplaces with long migrations not taken into account; *m*, half the proportion of long migrations; *k*, half the proportion of medium migrations; M_e, effective migration pressure; N_e, effective population size; *a*, local inbreeding level; *b*, linear systematic pressure coefficient. The "Change" column shows the changes in Malecot's isolation-by-distance parameters in the period between the 1950s and 1990s. The highest value of each Malecot's model parameter (irrespective of the year when it was recorded) was compared with its lowest value (in the other period of time). The signs at the values of the changes show the directions of the changes in Malecot's isolation-by-distance parameters with time: +, increase; –, decrease.

1990s, we determined the Malecot's isolation-by-distance parameters for each total district population (Tables 1, 2).

Analysis of the mean Malecot's model parameters at the municipality level for the 1950s showed the two analyzed districts of Kursk oblast (Prokhorovka and Pristen' raions) were characterized by the shortest (and close to each other) root mean square distances between spouses' birthplaces, with long migrations taken into account (σ) (13.66 and 9.92 km, respectively) or not taken into account (σ') (2.25 and 4.19 km), long migration rate (*m*) (0.010 and 0.007), and effective migration pressure (M_e) (0.042 and 0.045), which determined a high local inbreeding (*a*) (0.0073 and 0.0091). In the two analyzed districts of Voronezh oblast (Krasnoe and Rep'evka raions), the first three parameters were considerably higher, and the local inbreeding was lower. The populations of Krasnoe and Rep'evka raions were also similar to each other with respect to the estimated Malecot's isolation-by-distance parameters σ (22.74 and 33.23 km, respectively), σ' (9.87 and 12.38 km), *m* (0.015 and 0.017) M_e (0.066 and 0.071), and *a* (0.0039 and 0.0041).

When estimating the isolation-by-distance parameters for four total district populations in the 1950s, we observed similar tendencies. In general, Prokhorovka and Pristen' raions of Kursk oblast were characterized by lower σ (23.84 and 13.89 km) and σ' (4.82 and 3.22 km), *m* (0.009 and 0.003), and M_e (0.046 and 0.033) than Krasnoe and Rep'evka raions of Voronezh oblast, where these parameters were the following, respectively: σ, 28.98 and 38.05 km; σ', 9.15 and 12.06 km; *m*, 0.007 and 0.016; M_e, 0.048 and 0.072. However, Krasnoe and Rep'evka raions of Voronezh oblast had 1.3–1.7 times smaller effective population sizes (N_e) compared to Prokhorovka and Pristen' raions of Kursk oblast, which eventually determined approximately equal levels of local inbreeding (*a*) in the analyzed groups of districts (0.00033–0.00054).

Note that the σ' values at both the district and municipality levels in Prokhorovka and Pristen' raions of Kursk oblast in the 1950s were, on average, 3–4 km, which approximately corresponded to the size of a village. In Krasnoe and Rep'evka raions of Voronezh oblast, these values were 9–12 km, which was close to σ in districts of Kursk oblast (9–13 km, except for the district level in Prokhorovka raion) and approximately corresponded to the size of a rural municipality.

The population structure considerably changed in all populations studied between the 1950s and 1990s. This was characterized by an increase in σ, σ', *k*, and M_e and a decrease in *b* at both the municipality and district

Table 2. Changes in Malecot's isolation-by-distance parameters in Krasnoe and Rep'evka raions in the period between the 1950s and 1990s

Parameter	Krasnoe raion						Rep'evka raion					
	Values averaged over rural municipalities			Values for the total district population			Values averaged over rural municipalities			Values for the total district population		
	1950s	1990s	Change (1950s/1990s)	1950s	1990s	Change (1950s/1990s)	1950s	1990s	Change (1950s/1990s)	1950s	1990s	Change (1950s/1990s)
σ	22.74	37.93	*+1.67*	28.98	41.14	*+1.42*	33.23	68.77	*+2.07*	38.05	71.44	*+1.88*
σ'	9.87	24.34	*+2.47*	9.15	26.71	*+2.92*	12.38	45.25	*+3.66*	12.06	45.62	*+3.78*
m	0.015	0.021	*+1.40*	0.007	0.022	*+3.14*	0.017	0.016	*–1.06*	0.016	0.018	*+1.13*
k	0.152	0.354	*+2.33*	0.159	0.360	*+2.26*	0.144	0.299	*+2.05*	0.153	0.299	*+1.95*
M_e	0.066	0.123	*+1.86*	0.048	0.127	*+2.65*	0.071	0.103	*+1.37*	0.072	0.107	*+1.49*
N_e	1205	628	*–1.92*	10222	5357	*+1.91*	1570	900	*–1.74*	10581	6224	*–1.70*
a	0.0039	0.0039	*1.00*	0.00051	0.00037	*–1.38*	0.0041	0.0044	*+1.10*	0.00033	0.00038	*+1.15*
b	0.1631	0.0219	*–7.45*	0.0340	0.0189	*–1.80*	0.0485	0.0102	*–4.15*	0.0294	0.0101	*–2.91*

levels. Because of these changes, together with a decrease in the effective population size (N_e), the local inbreeding level has remained almost unchanged during the past 50 years. The proportion of long migrations (m) remained the same in some populations and somewhat increased in others.

Note that the changes in Malecot's isolation-by-distance parameters during the past two generations were the smallest in Krasnoe raion. Rep'evka and Prokhorovka raions ranked next in order of the intensity of changes. The largest changes were observed in Pristen' raion.

By the 1990s, differences in Malecot's isolation-by-distance parameters were formed within each pair of the analyzed districts that formerly belonged to the same region, namely, between Prokhorovka raion (currently of Belgorod oblast) and Pristen' raion (which remained in Kursk oblast) and between Krasnoe raion (currently of Belgorod oblast) and Rep'evka raion (which remained in Voronezh oblast). In the 1950s, Malecot's isolation-by-distance parameters for Prokhorovka raion were higher than those for Pristen' raion; by the 1990s, considerable changes in these parameters, especially in Pristen' raion, led to reversion of differences between these populations, and Malecot's isolation-by-distance parameters for Pristen' raion became substantially higher than in Prokhorovka raion. Isolation-by-distance parameters for Krasnoe raion were lower than those for Rep'evka raion in both the 1950s and the 1990s.

We found that the districts that were included to Belgorod oblast in 1954 (Prokhorovka and Krasnoe raions) already had, by the 1990s, similar Malecot's isolation-by-distance parameters (σ and σ') that were lower than those for the neighboring districts of Kursk and Voronezh oblasts. The σ values for Prokhorovka and Krasnoe raions of Belgorod oblast in the 1990s were 51.99 and 41.14 km, respectively, whereas its values in Rep'evka raion of Voronezh oblast and Pristen' raion of Kursk oblast were 71.44 and 87.60 km, respectively. The σ' values in Prokhorovka and Krasnoe raions of Belgorod oblast, Rep'evka raion of Voronezh oblast, and Pristen' raion of Kursk oblast were 32.25, 26.71, 45.62, and 57.70 km, respectively.

Note that σ' in Prokhorovka and Krasnoe raions of Belgorod oblast in the 1990s (24–32 km) approximately corresponded to the size of an administrative district, whereas this parameter in Rep'evka raion of Voronezh oblast and Pristen' raion of Kursk oblast was 38–57 km, which is about the size of two districts.

Our data agree with earlier estimations of Malecot's parameters in Kursk oblast [8]. During a period of 30 years, σ, σ', m, k, and M_e for the rural population of Kursk oblast increased, while b and N_e decreased [8].

The root mean square distances between spouses' birthplaces has been found to increase in the Moscow

population in the period from the late 19th century and mid-20th century [16–18]. The authors of that studies demonstrated that, compared to the early 20th century, the isolation by distance (b) was decreased by a factor of two by the mid-20th century and by a factor of three (from 0.0016 to 0.0005) by the late 20th century. Similar trends in Malecot's isolation-by-distance parameters were characteristic of some Ukrainian cities (Poltava, Kharkov, and Donetsk) during the past several decades [18–21].

Note that analysis of Malecot's isolation-by-distance parameters for the populations of Prokhorovka and Krasnoe raions of Belgorod oblast at the district level carried out in the 1990s showed that two independent methods for estimating local inbreeding, the isonymy method and the method based on Malecot's isolation-by-distance model, yielded about the same results. The F_{st} and Malecot's local inbreeding (a) in Prokhorovka raion were 0.00052 and 0.00029, respectively; in Krasnoe raion, these values were 0.00138 and 0.00037, respectively, which suggests that the local and random inbreeding coefficients are similar in terms of genetic sense. Our data entirely agree with the results of earlier studies in Kostroma oblast, where the correlation coefficient between Malecot's local inbreeding (a) and Wright's random inbreeding (F_{st}) was $r = 0.482$ [1, 7], Adygean Autonomous Oblast of Karasnodar krai ($F_{st} = 0.00991$, $a = 0.00397$) [10], Arkhangel'sk oblast ($F_{st} = 0.000358$, $a = 0.00565$ in Vinogradovskii raion and $F_{st} = 0.000361$, $a = 0.000472$ in Krasnoborsk raion) [22], the Republic of Marii El ($r = 0.85 \pm 0.17$) [9], Kursk oblast ($F_{st} = 0.000650$, $a = 0.000201$) [8], and the Republic of Chuvashia ($F_{st} = 0.00027$, $a = 0.000189$ in the urban population and $F_{st} = 0.00043$, $a = 0.000318$ in the rural population) [12].

Thus, analysis of the changes in Malecot's isolation-by-distance parameters in four districts of the Central Chernozem region during the past 50 years at different population levels (rural municipality and district) has led us to the following conclusions. *First*, during the lifespan of two generations, the root mean square distances between spouses' birthplaces, with long migrations taken into account (σ) or not taken into account (σ'), the proportion of medium migrations (k), and the effective migration pressure (M_e) have considerably increased, and the linear systematic pressure coefficient (b) has decreased. The local inbreeding level (a) has remained practically unchanged during the past 50 years because of the aforementioned changes, on the one hand, and a decrease in the effective population size (N_e), on the other hand. The changes in Malecot's isolation-by-distance parameters were the largest in Pristen' raion and the smallest in Krasnoe raion.

Second, most marriages were contracted between residents of the same village or rural municipality in the 1950s: the root mean square distance between spouses' birthplaces, with long migrations not taken into account (σ'), varied from 2 to 12 km (the average distance was 5–7 km). By the 1990s, the migration activity increased, with marriage migrations within one or two districts being the most prevalent (the root mean square distance between spouses' birthplaces, with long migrations not taken into account (σ'), varied from 24 to 58 km in the populations studied). *Third*, the change in the regional administrative structure affected the population genetic structure. In the 1950s, the administrative districts of both Kursk and Voronezh oblasts were similar in differentiation parameters, whereas the two oblasts substantially differed in this respect. At present, the districts that were included to Belgorod oblast in 1954 have similar values of some parameters of Malecot's isolation-by-distance model, and they are lower than those for the neighboring districts that remained in Kursk and Voronezh oblasts.

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