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Relationship between autumn numbers of the Coal Tit *Parus ater*, air temperatures and North Atlantic Oscillation index

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Abstract: Sokolov, L.V., Kosarev, V.V., Fedoseeva, N.V., Markovets, M.Yu., Shapoval, A.P. & Yefremov, V.D. (2003): Relationship between autumn numbers of the Coal Tit *Parus ater*, air temperatures and North Atlantic Oscillation index. Avian Ecol. Behav. 11: 71-88.

Correlation analysis of the long-term data (1958-2000) showed a significant relationship between numbers of Coal Tits *Parus ater* on the Courish Spit on the Baltic and mean winter air temperatures (December, January and February) in different regions of Eurasia from Britain to Sakhalin. Spring monthly temperatures (March and April) showed a significant correlation in some regions only. We also found a significant positive relationship between July air temperature in different regions of Eurasia and autumn bird numbers. Of all autumn months (September, October, November), the strongest positive correlation with autumn numbers was typical of October. It occurred over a huge area from Kaliningrad to the river Ob. A significant positive relationship of autumn Coal Tit numbers on passage on the Courish Spit with North Atlantic Oscillation (NAO) index was found for January, February, and August. It is suggested that in mild winters in a large part of the species' range, significantly more adults survive than in colder winters. This increases the numbers of breeding individuals who produce more offspring. We suggest that the bulk of Coal Tits captured on the Courish Spit in irruptive years originate not in the Baltic area, but in the vast area of European Russia and possibly Western Siberia.

Key words: Coal Tit, irruption, autumn numbers, migration, ambient temperature, North Atlantic Oscillation (NAO), climate, passerines.

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1. Introduction

The Coal Tit *Parus ater* has a large distribution range, stretching from Ireland to Kamchatka (Cramp & Perrins 1993, see Fig. 1). The Coal Tit is a typical irruptive species whose numbers fluctuate greatly between the years in different parts of Europe (Biber 1972, Sherreer 1972, Löhrl 1977, Cramp & Perrins 1993). The numbers of Coal Tits captured in Rybachy-type stationary traps on the Courish

Spit in autumn vary between the years from several individuals to several thousand individuals (Sokolov et al. 2002). Similar data are available from other parts of the Eastern Baltic. In Kabli (Estonia) annual totals of Coal Tits captured in stationary traps during autumn passage varied between 21 and 6075 per season (A. Leivits, pers. comm.), in Pape (Latvia), from 17 to 18616 individuals (J. Baumanis, pers. comm.).

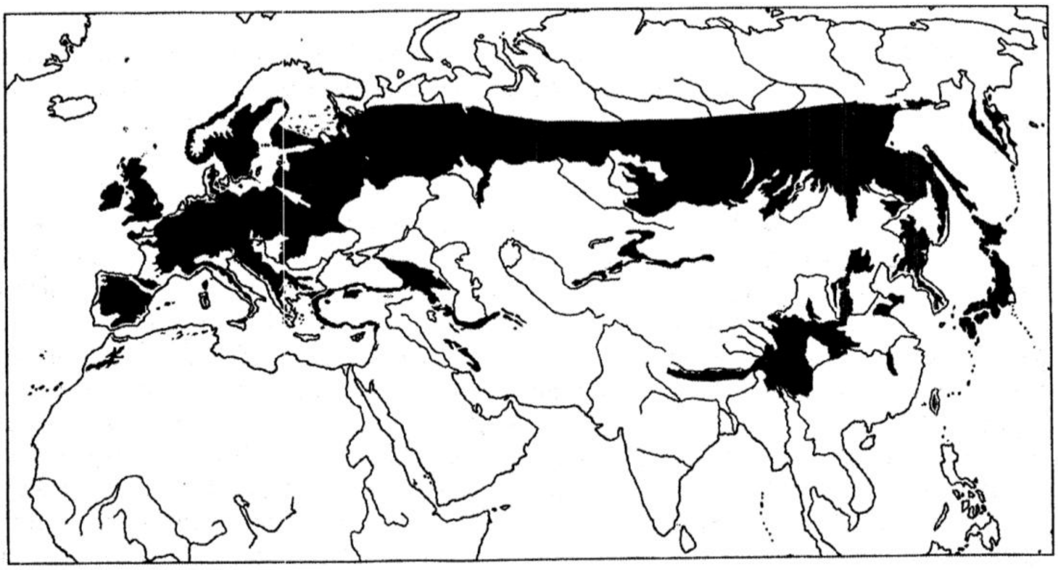

Figure 1. Breeding range of the Coal Tit (fromHaffer 1993). Trapping area is shown by an arrow.

These strong fluctuations of autumn numbers in the Coal Tit raise two questions: (1) which environmental variables are responsible for such variation; (2) from what parts of Eurasia can Coal Tits captured in the Baltic area during irruptions originate?

To some extent, we attempted to answer these questions elsewhere (Sokolov et al. 2002, Markovets & Sokolov 2002). In these papers we however could not analyse the relationship of autumn Coal Tit numbers on the Courish Spit, firstly, with seasonal temperatures in the vast area to the east of the Baltic, secondly, with NAO (North Atlantic Oscillation) index. NAO index is a good estimator of the changes in temperature regime and precipitation, especially in winter and early spring in the Northern hemisphere (Hurrell et al. 2001, Mashall et al. 2001, Fowler & Kilsby 2002).

The main aim of this paper was to find correlations: (1) between long-term dynamics of autumn Coal Tit numbers on the Courish Spit and fluctuations of seasonal temperatures in different parts of the species' breeding range; (2) between the dynamics of autumn Coal Tit numbers and NAO index.

2. Material and methods

Since 1957, annual trapping of birds is conducted without interruptions in Rybachy-type stationary traps (Payevsky 2000) between late March and early November at the "Fringilla" field site of the Biological Station Rybachy on the Courish Spit on the Baltic (55°05′N, 20°44′E). In this paper, we analyse trapping figures of Coal Tits in 1958-2000 in autumn, between 15 August and 31 October (Fig. 2). The bulk of Coal Tits trapped are first-autumn birds, the proportion of adults varying between 0 and 5.5% in different years, 1.3% on average (Markovets & Sokolov 2002).

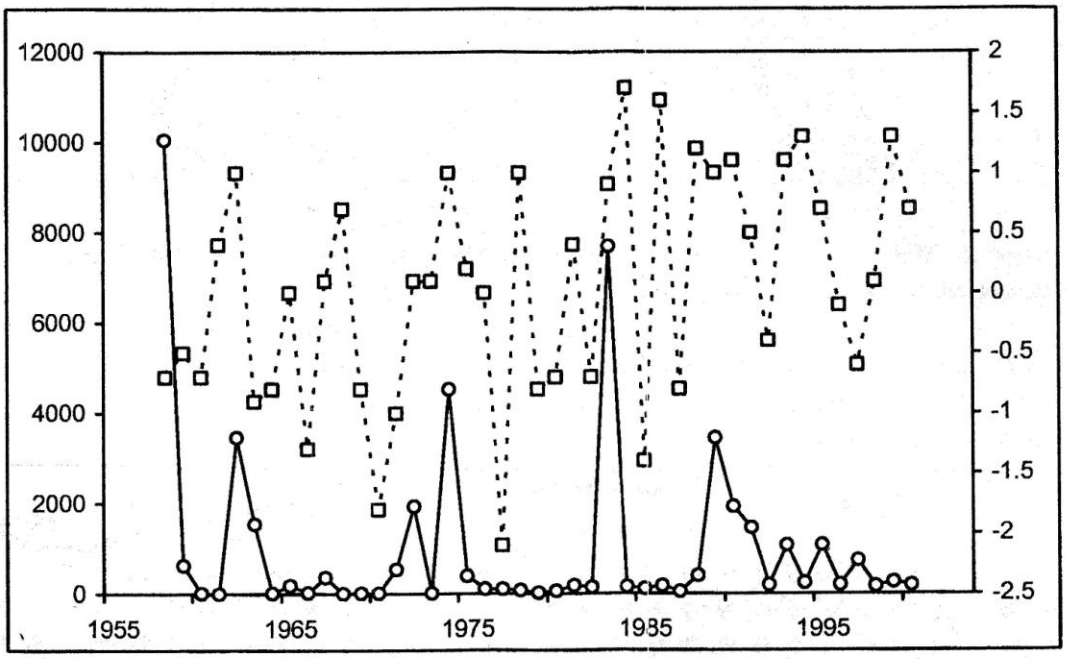

Figure 2. Long-term dynamics of autumn Coal Tit numbers on the Courish Spit and January NAO index. Open circles - number of birds captured in large traps per autumn (left Y-axis), open squares - January NAO index (right Y axis).

For the analysis of correlation we used, firstly, long-term data on the mean monthly air temperatures at 100 weather stations in Russia from Kaliningrad Region to Kamchatka in 1958-1989 (Fig. 3). These data are available in the World Wide Web: <http://cdiac.esd.ornl.gov/ftp/>.

Secondly, we analysed temperature data of the monthly gridded dataset on 5 × 5 degrees resolution on the whole globe in 1958-2000 (<http://www.ncdc.noaa.gov/>). From this database, we used temperature data from Europe and Northern Asia (Fig. 4). This dataset contains gridded temperature anomalies for mean temperature from the GHCN V2 monthly temperature data sets. Each month of data consists of 2592 gridded data points produced on a 5 × 5 degree basis for the entire globe (72 longitude × 36 latitude grid boxes).

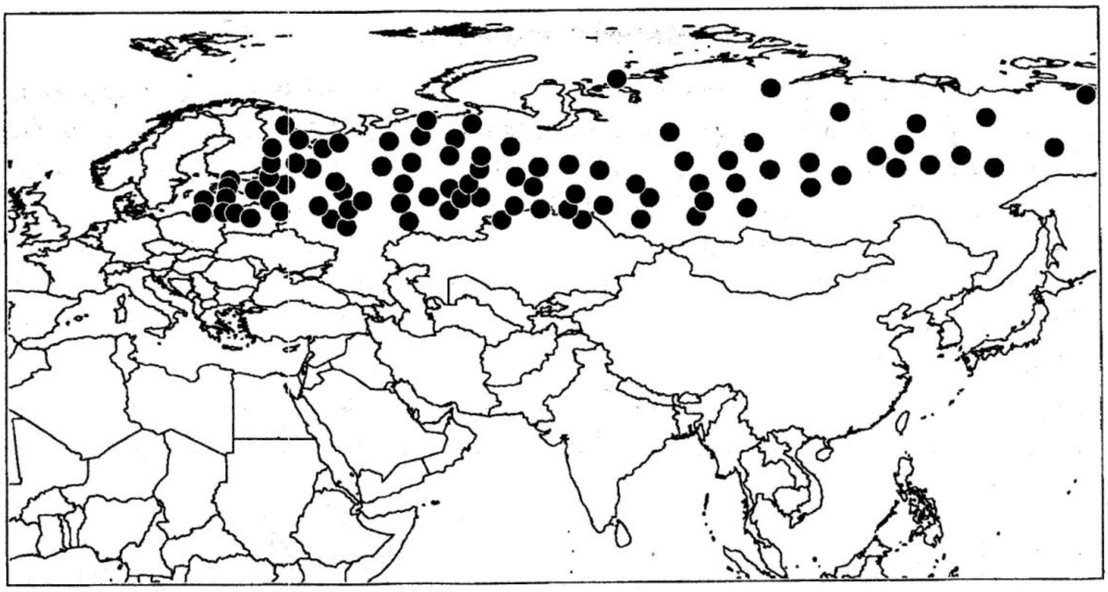

Figure 3. Map of Russia's weather stations whose data were used in this paper. Each weather station is denoted by a circle.

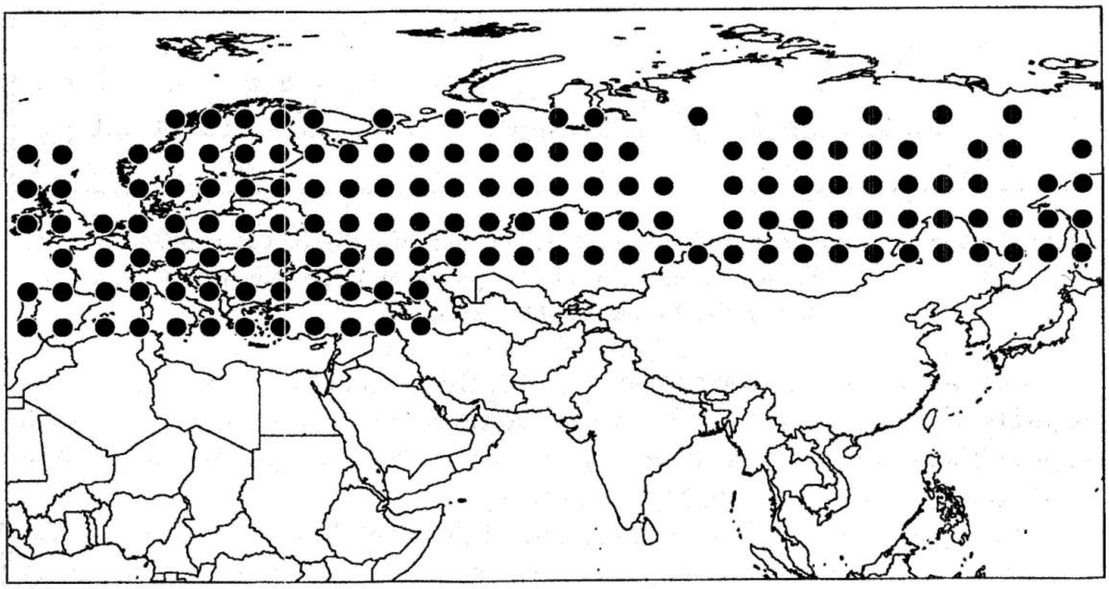

Figure 4. Map of sectors for which temperature data were used. The centre of each sector is shown by a circle.

Weather and climate in Eurasia and North America are to a large extent governed by the atmospheric circulation over the North Atlantic represented by the two low and high pressure systems (Girs 1975, Kondratovich 1977, Smirnov et al. 1998, Mashall et al. 2001, Fowler & Kilsby 2002). The quasi-stationary centre of low atmospheric pressure situated to the SW of Iceland is usually called Iceland depression, or Iceland minimum. The quasi-stationary centre of high pressure is localised near the Azores and is called Azores anticyclone, or Azores maximum. The difference of the normalised sea-level pressures between these two centres is defined as the North Atlantic Oscillation (NAO) index. This index reflects the dynamics of atmospheric circulation not only over the North Atlantic, but over the vast areas of Europe, North America, Northern Asia and the Arctic Ocean (Hurrell et al. 2001). Westerly movements of air masses from the Atlantic, primarily in winter, to a great extent govern temperature and precipitation regime and drainage in these areas, ice conditions and water level in the Baltic and Barents Seas (Baidal & Neushkin 1994, Qian et al. 2000, Goldberger 2001, Cullen et al. 2002, Fowler & Kilsby 2002). We used monthly NAO index and index pooled over several months. Monthly NAO indices are archived at the National Oceanic and Atmospheric Administration's Climate Prediction Center website (www.cpc.ncep.noaa.gov/data/teledoc/nao.html; April 2002).

We used both Pearson and Spearman correlation (Lloyd & Ledermann 1984). Spearman correlation coefficients were calculated between autumn numbers of Coal Tits and the mean monthly temperatures from each weather station and from the centre of each gridded dataset cell. If the relationship was significant, the weather station or cell was plotted on the map.

3. Results

3.1. Relationship between autumn trapping figures and seasonal air temperatures

3.1.1. Weather station data

A significant positive relationship between autumn numbers of Coal Tits trapped on the Courish Spit in 1958-1989 and mean monthly temperatures in different Russia's regions was found for December (preceding year), January, February, July, September, and October. The higher the temperature in these months was, the larger Coal Tit numbers were recorded on the Courish Spit in autumn. The mean winter temperature (pooled December - February) is related to autumn Coal Tit numbers on the Courish Spit over a vast area from Kaliningrad Region to Lake Baikal (Fig. 5).

No significant relationship was found with spring (April and May) air temperatures in any of Russia's regions analysed. Only six regions between Novosibirsk and Baikal showed a relationship to the March temperature.

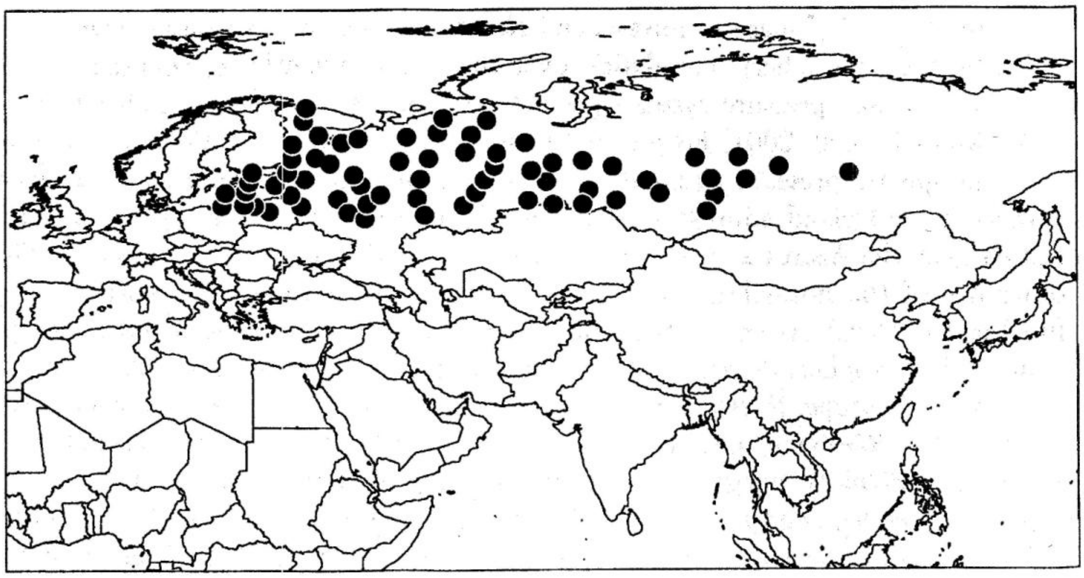

Figure 5. Position of weather stations (circles) which showed a significant ($p < 0.05$) positive relationship between winter (December - February) air temperatures and autumn Coal Tit numbers on the Courish Spit.

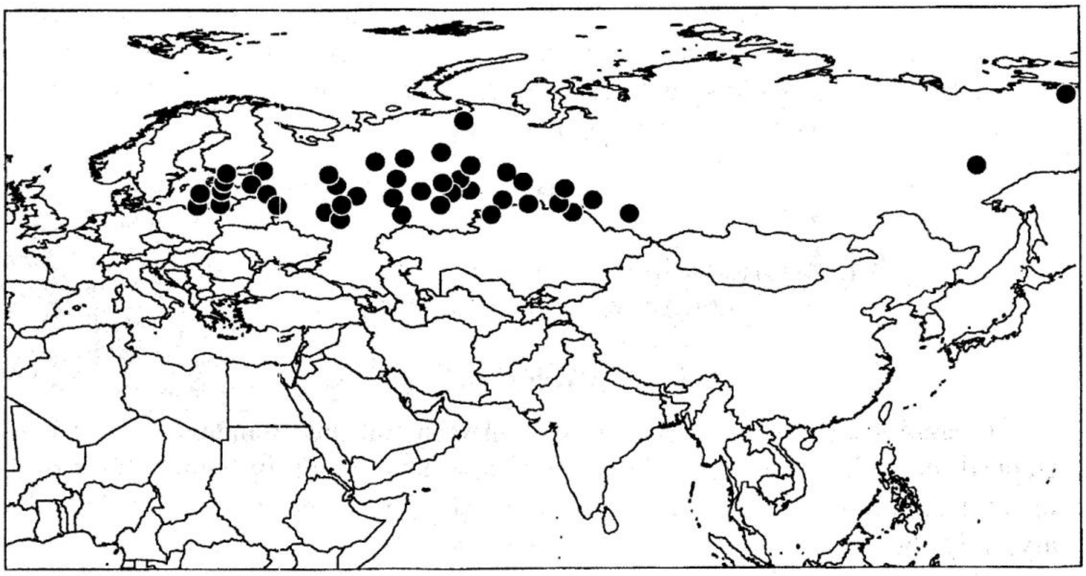

Figure 6. Position of weather stations (circles) which showed a significant ($p < 0.05$) positive relationship between autumn (October) air temperatures and autumn Coal Tit numbers on the Courish Spit.

Of all autumn temperatures (September, October, November), the strongest correlation with autumn trapping figures occurred for October over a large area from Kaliningrad to river Ob (Fig. 6).

3.1.2. Gridded dataset

The analysis of gridded dataset showed a significant positive relationship to autumn Coal Tit numbers on the Courish Spit in 1958-2000 for the mean temperatures of January, February, July, and October (Fig. 7, 8, 10, 11). Some areas of Eurasia showed a relationship to the spring months (March and April, Fig. 9).

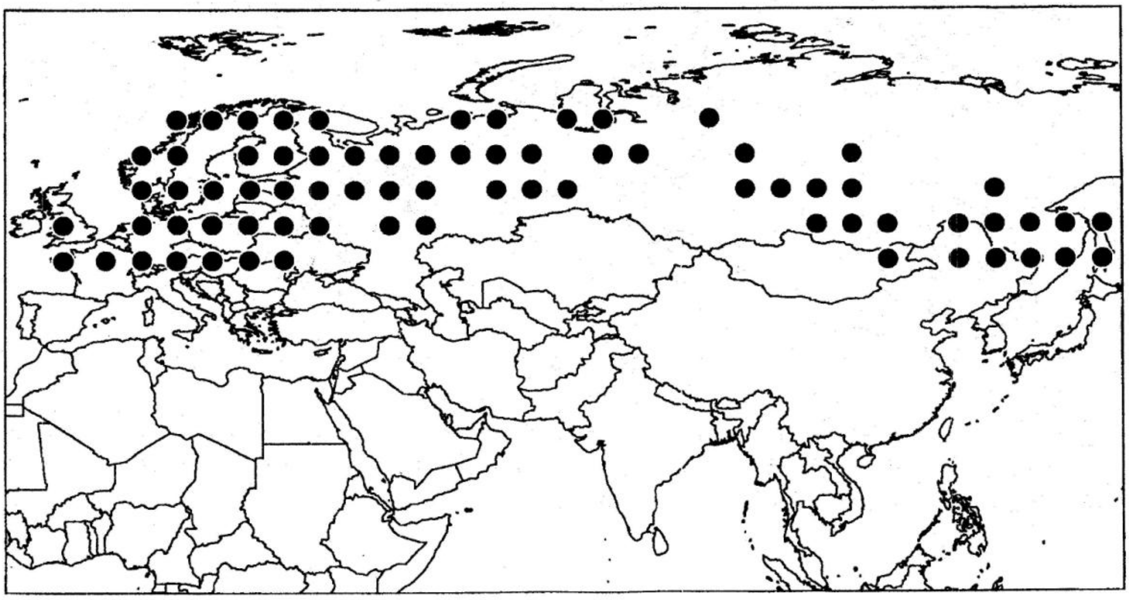

Figure 7. Position of sectors (circles show their centres) which showed a significant positive relationship between January air temperature and autumn Coal Tit numbers on the Courish Spit.

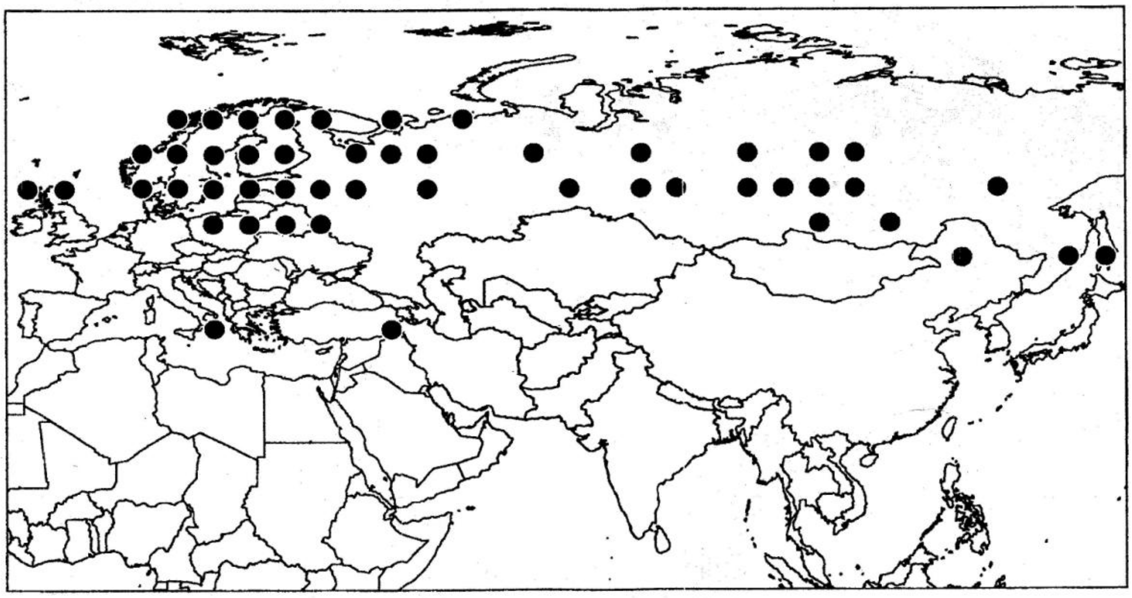

Figure 8. Position of sectors (circles show their centres) which showed a significant positive relationship between February air temperature and autumn Coal Tit numbers on the Courish Spit.

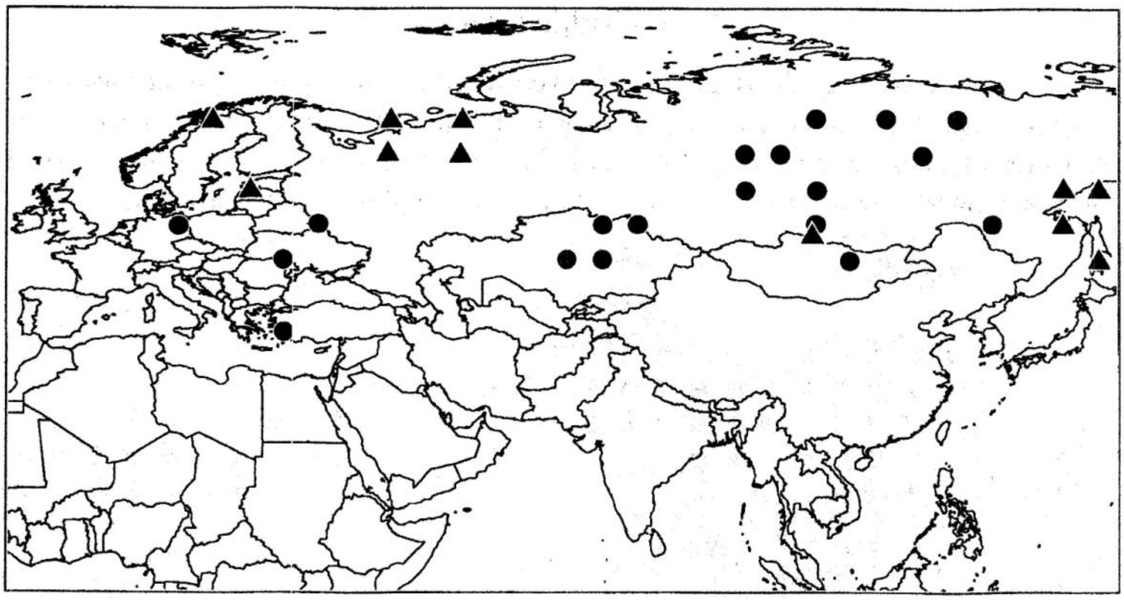

Figure 9. Position of sectors which showed a significant positive relationship between spring (March and April) air temperature and autumn Coal Tit numbers on the Courish Spit. Signs show sector centres: circles – March, triangle – April.

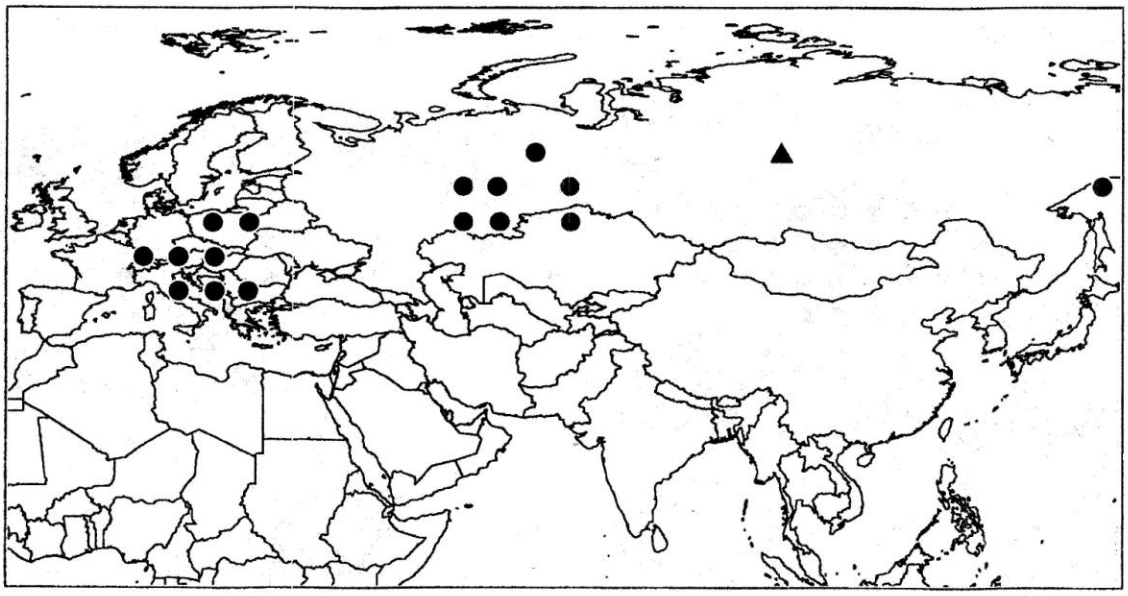

Figure 10. Position of sectors which showed a significant relationship between July air temperature and autumn Coal Tit numbers on the Courish Spit. Signs show sector centres: circles – positive relationship, triangle – negative relationship.

June temperatures showed both positive (middle Ob and Irtysh areas) and negative (Baltic area) relationships. The whole winter period pooled (December - February), a significant relationship is revealed over the whole Northern Eurasia, from Britain to Sakhalin (Fig. 7, 8). No significant relationship was found to May temperatures in any of these regions. A positive relationship of Coal Tit autumn numbers with autumn temperatures, primarily to the temperature of October, was found over the area from the Baltic to Sakhalin (Fig. 11).

The results of two correlation analyses based on the data from weather stations and on the gridded dataset showed a good agreement.

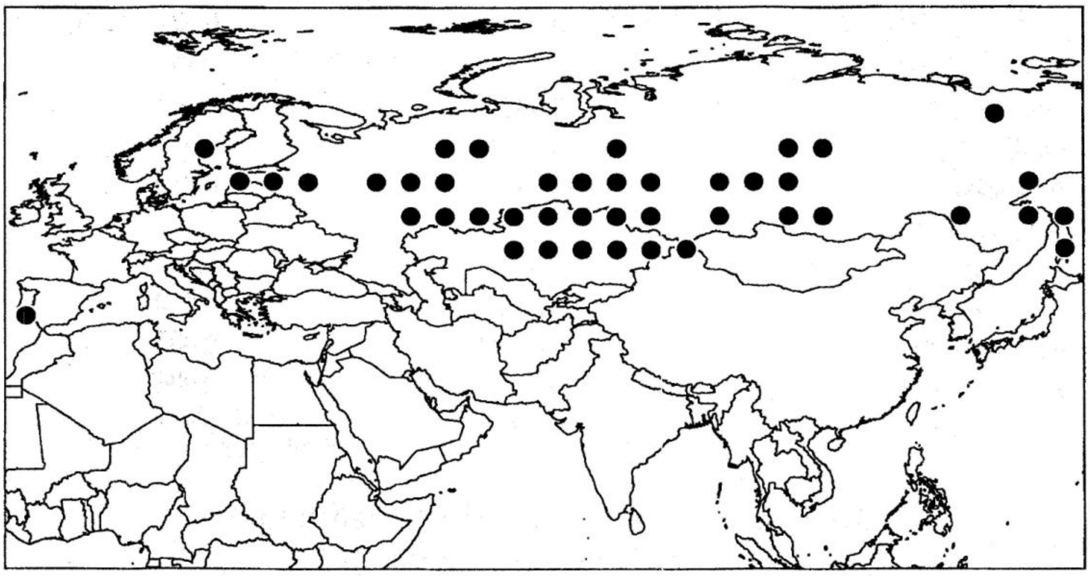

Figure 11. Position of sectors (circles show their centres) which showed a significant positive relationship between October air temperature and autumn Coal Tit numbers on the Courish Spit.

3.2. Relationship between autumn bird numbers and seasonal NAO indices

The relationship between autumn numbers of Coal Tits on the Courish Spit and the NAO index was analysed for 12 months, including November and December of the previous year, and several pooled periods (Tab. 1).

A significant positive relationship was found only for January, February, and August. The higher the NAO index in these months was, the more Coal Tits were captured in stationary traps on the Courish Spit in autumn. Of the pooled periods, a similar positive relationship was only found for January-February (Tab. 1).

Table 1. Relationship between autumn Coal Tit numbers on the Courish Spit and NAO index, 1958-2000 (r_s – Spearman's rank correlation coefficient: *$p < 0.05$, **$p < 0.01$).

Months	r_s	p
November (previous year)	-0.013	0.935
December (previous year)	0.111	0.485
January	0.410**	0.007
February	0.320*	0.039
March	0.139	0.378
April	-0.042	0.792
May	-0.036	0.822
June	-0.118	0.455
July	0.069	0.662
August	0.321*	0.038
September	0.186	0.238
October	0.228	0.146
November	0.063	0.691
December	-0.026	0.872
January-February	0.426**	0.005
February-March	0.270	0.084
March-April	-0.085	0.591

3.3. Relationship of seasonal air temperatures with the NAO index

A significant positive relationship between seasonal temperatures in different parts of Eurasia with the NAO index was revealed for January, February, March, July, September and December (Fig. 12-14). In these months higher air temperatures coincide with the high NAO index values, to a varying degree and in different parts of Eurasia. This is especially typical of winter (December - February), March, and September.

For April, May, June, August, October, and November both regions with positive and those with negative significant relationship between air temperature and the NAO index exist. Positive relationships are mainly typical of Northern Europe (British Isles, Scandinavia and NW Russia, Fig. 15, October). Negative relationships were revealed for Southern Europe and the Southern Urals (October).

Fig. 16 shows the fields of ground-level pressure anomalies averaged for the cold half-year (October - March) typical of the extreme warm and extreme cold months in St. Petersburg. The opposite thermal conditions were due to the opposite localisation of the foci of cyclonic and anticyclonic activity. Mild winters are caused by the activation of the cyclonic, and cold winters of the anticyclonic processes north of 50° N. Positive NAO index values reflect the situation in Europe in winter and early spring, when warm air masses move from the Atlantic Ocean and increase temperatures and precipitation in Europe and Northern Asia. Conversely, negative NAO index values suggest weaker westerlies and thus lower temperature and precipitation in Eurasia.

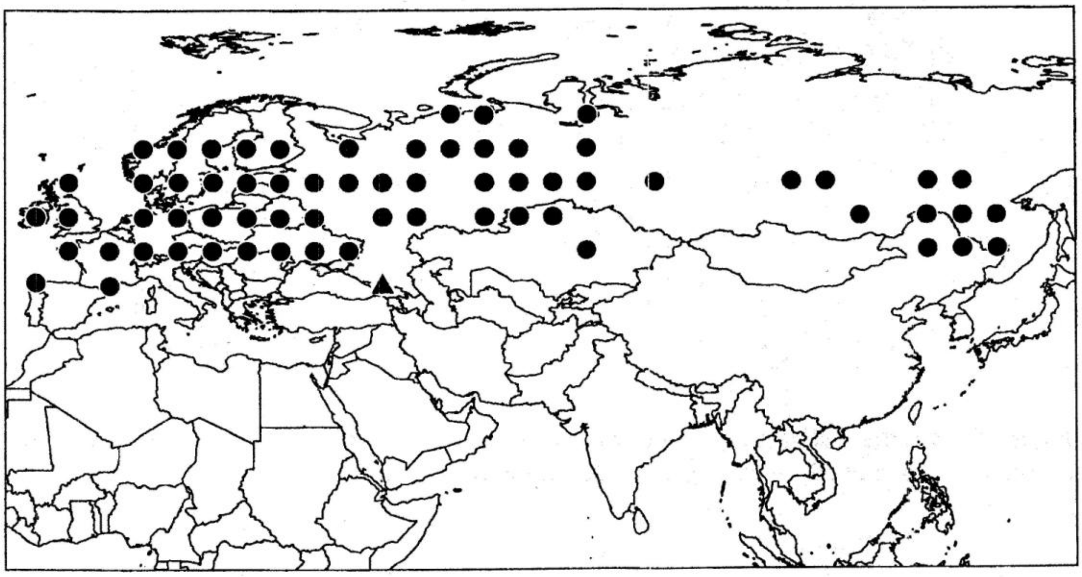

Figure 12. Position of sectors which showed a significant relationship between January air temperature and January NAO index. Signs as in Fig. 10.

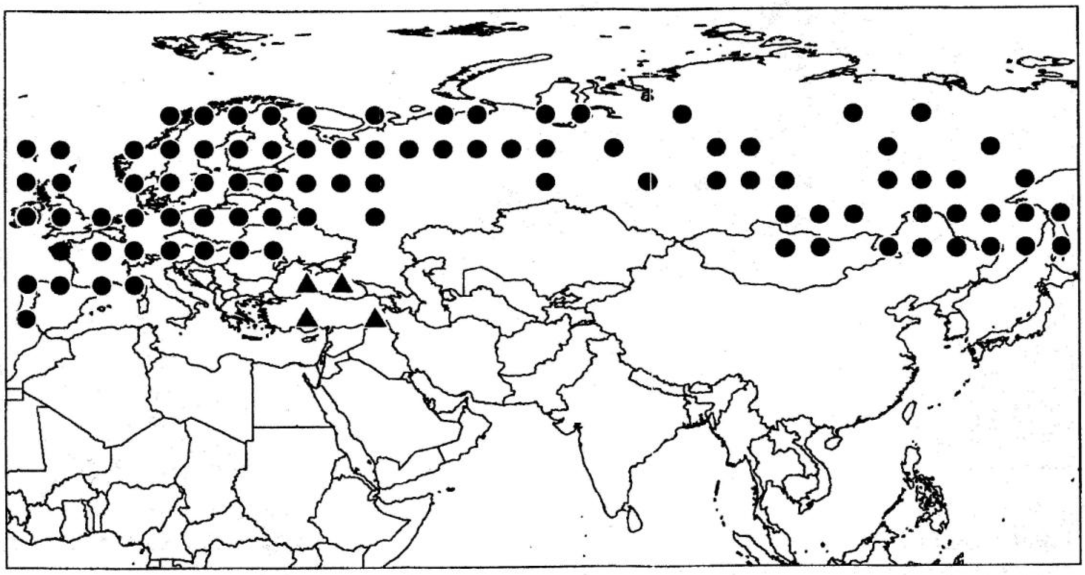

Figure 13. Position of sectors which showed a significant relationship between March air temperature and March NAO index. Signs as in Fig. 10.

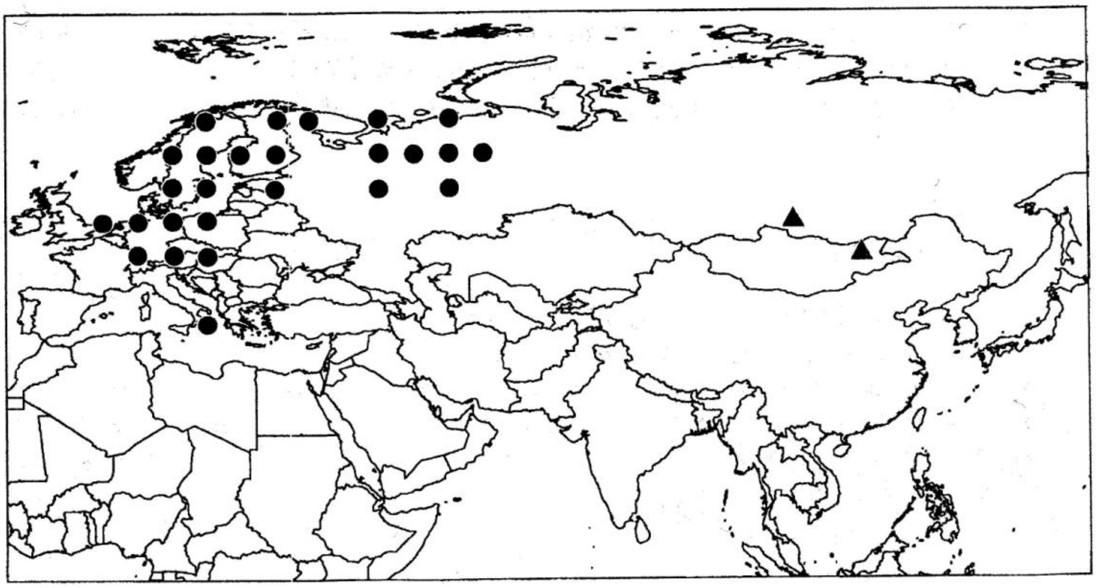

Figure 14. Position of sectors which showed a significant relationship between September air temperature and September NAO index. Signs as in Fig. 10.

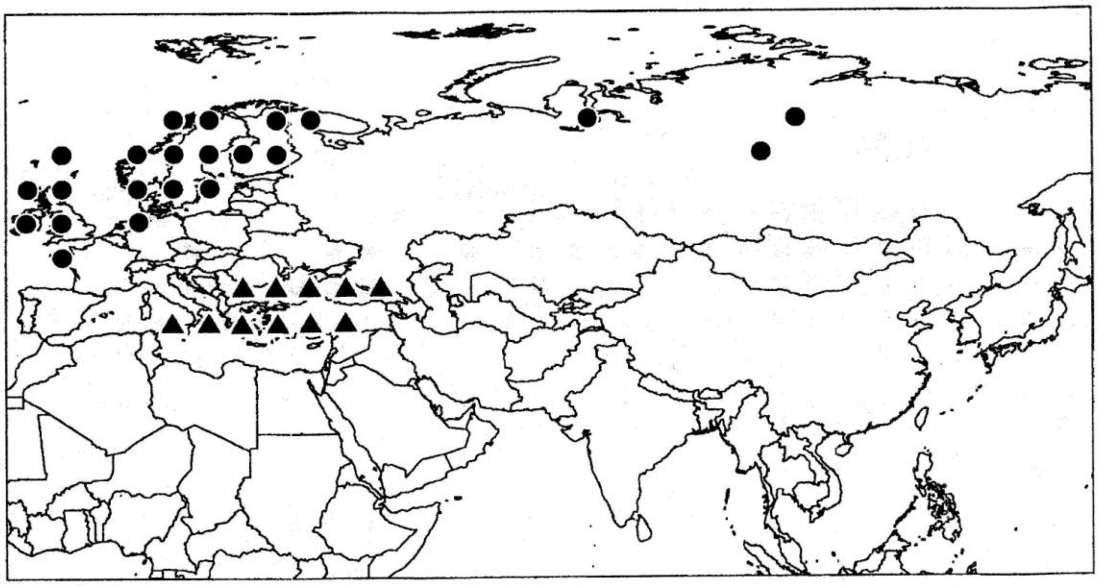

Figure 15. Position of sectors which showed a significant relationship between October air temperature and October NAO index. Signs as in Fig. 10.

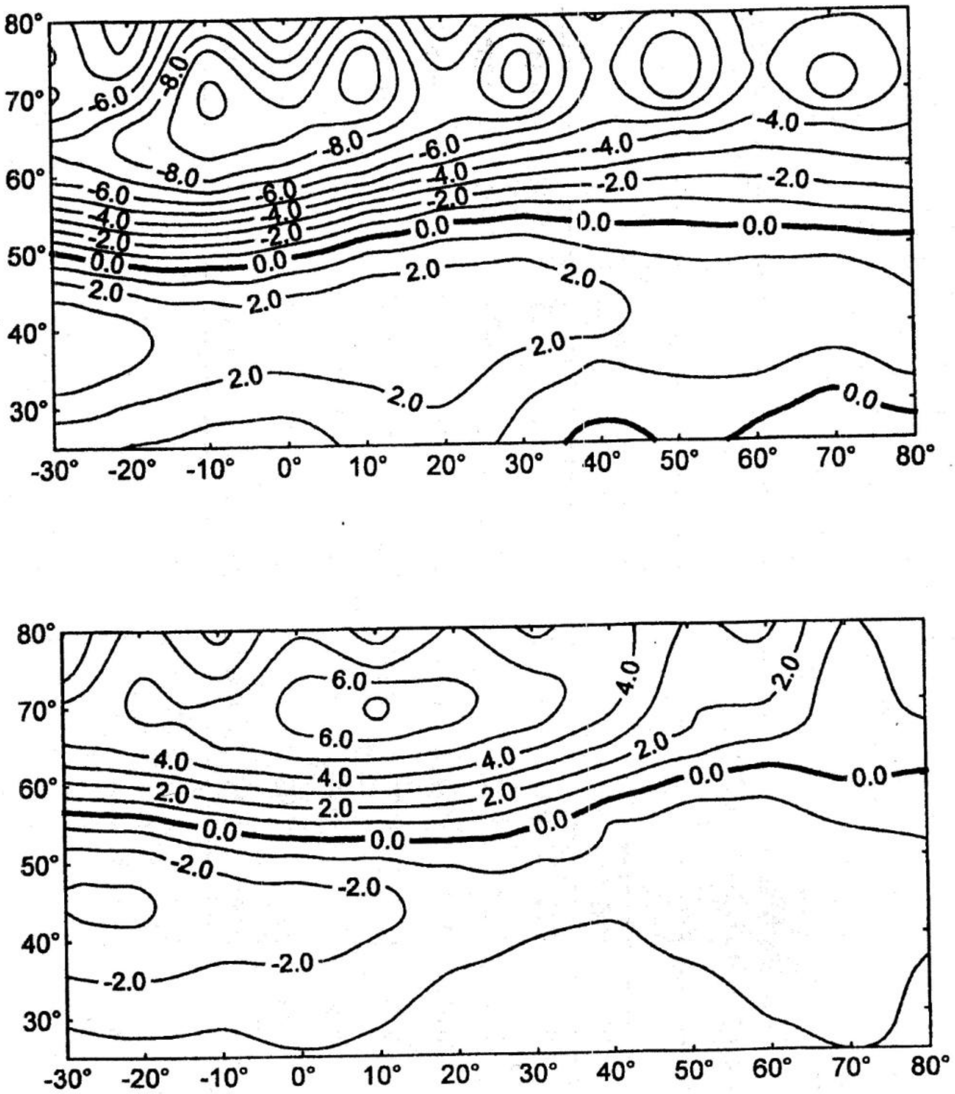

Figure 16. Surface pressure anomalies averaged for cold half-year (October-March) typical of the extreme warm and cold years in St.Petersburg.

The dependence of the thermal conditions in Europe on the oscillations of the North Atlantic centres of atmospheric activity is confirmed by correlation coefficients in a number of Baltic stations over 120 years (Tab. 2). Over the 30-year period used by us the strongest relationship between thermal regime in the Baltic area and North Atlantic Oscillation was typical of winter when the Iceland centre is most active. These relationships are most obvious in November - March when the deep Iceland minimum causes strong westerly movements of air masses over the eastern North Atlantic and in general provokes mild winters in Northern Eurasia. A weakening of the Iceland depression is accompanied by stronger meridional processes and consequently colder winters in Eurasia.

Table 2. Pearson's correlation coefficient ($r_{95\%} = \pm0.18$) between the mean monthly temperatures at Baltic stations and the respective NAO indices, 1873-2000. Significant coefficients ($p < 0.05$) are marked by an asterisk.*

Stations	Months											
	01	02	03	04	05	06	07	08	09	10	11	12
Stockholm	0.52*	0.45*	0.59*	0.16	0.22*	0.11	0.28*	0.37*	0.34*	0.33*	0.37*	0.41*
Helsinki	0.44*	0.45*	0.58*	0.13	0.22*	0.07	0.33*	0.34*	0.26*	0.21*	0.29*	0.25*
St.Petersburg	0.41*	0.38*	0.53*	0.05	0.13	-0.04	0.25*	0.18*	0.10	0.14	0.14	0.16
Riga	0.44*	0.42*	0.58*	0.04	0.21*	0.01	0.24*	0.28*	0.24*	0.19*	0.28*	0.18*
Vilnius	0.36*	0.39*	0.53*	0.02	0.11	-0.06	0.15	0.28*	0.21*	0.18*	0.24*	0.12
Kaliningrad	0.45*	0.38*	0.58*	0.01	0.25*	0.02	0.23*	0.33*	0.30*	0.23*	0.27*	0.23*
Copenhagen	0.53*	0.47*	0.61*	0.15	0.18*	0.10	0.18*	0.35*	0.31*	0.35*	0.37*	0.41*

4. Discussion

Even though adult Coal Tits are sedentary, first-autumn birds may perform migratory movements over large distances, up to 2000-3000 km (Zink 1981, Bolshakov et al. 2001). The numbers of individuals participating in these movements may be very high, but the movements are irregular.

Several hypotheses were suggested to explain the irregular autumn migration of Coal Tits. Some hypotheses explain the irruptions mainly by food shortage (Lack 1954, Formozov 1965, Svärdson 1957, Karelin & Azovsky 1988). Svärdson (1957) believes that irruptive species can migrate each year, but when food is abundant in the breeding area migratory activity is limited or non-existent. Ryabitsev (2001) suggests that if food (seeds of conifers) is abundant, most Coal Tits in the Urals and Western Siberia are sedentary. If the crop fails, broad nomadic movements occur, sometimes - mass migration, mainly to the south and back. It is believed that if population density is high after several successive years with good seed crops, food shortage might occur in the breeding areas causing mass emigration to other parts (Curry-Lindahl 1975).

Another group of hypotheses suggests that autumn migrations in the Coal Tit occur annually and are normal migrations with return. These migrations sometimes occurring as irruptions are mainly related not to food shortage but to successful breeding when many young are recruited (Bardin et al. 1986, Bardin & Rezviy 1988, Sokolov et al. 2002). Most popular is the hypothesis of the trigger mechanism switching on migratory restlessness in irruptive species through intense social contacts of young birds (Svärdson 1957, Alerstam 1990). We have discussed these hypotheses in much detail elsewhere (Sokolov et al. 2002, Markovets & Sokolov 2002). In this paper, we are only going to discuss the possible impact of some weather variables which could influence survival rate and breeding performance of Coal Tit populations in Eurasia.

Our results show that the strongest positive correlation between autumn numbers of Coal Tits on the Courish Spit and mean monthly temperatures is typical of winter. It is logical to assume that when winters across the bulk of the range are mild, more adults survive than in cold winters. This may increase breeding density and thus enhance production of more young. This assumption is further supported by the positive relationship of Coal Tit numbers on autumn passage in the Eastern Baltic to winter NAO index values (Tab. 1). However, it cannot be ruled out that weather conditions in winter and spring may influence accessibility of spruce and pine seeds which may in its turn govern Coal Tit numbers in different years. Spruce cones open in winter, pine cones in spring. Seed availability increases food caching success in winter and early spring. These caches may be used when feeding the young, as shown for the Varied Tit *Parus varius* (Higuchi 1977).

Breeding density in sedentary and partially migratory species is known to be strongly dependent on winter weather (Senar & Copete 1995, Newton et al. 1998, Peach et al. 1998). Winters with much snow and low air temperatures caused a crash of the Tree Sparrow *Passer montanus* population in Poland (Pinowski et al. 1981). The original numbers was not restored in the optimal habitats until 2-3 years later. Similar relationships were found in other countries. Mansfeldt (in Pinowski et al. 1981) found a drop in Tree Sparrow numbers in Scotland after cold winters in 1939-1940. In Eastern Europe Tree Sparrow numbers dropped by 50% after the cold and snowy winters of 1975/76 and 1976/77. In the northern part of the range, fluctuations of numbers may be 10-fold. In Leningrad Region the numbers dropped not only after cold winters, but also after an unsuccessful breeding period when summer was cold and rainy (Pinowski et al. 1981).

We found a significant positive correlation between winter air temperatures and winter NAO indices over a huge area, from the British Isles to Sakhalin (Fig. 12, Tab. 2). Positive NAO indices are known to reflect the situation when warm air masses move from the Atlantic Ocean and cause higher temperature and precipitation in NW Europe in winter (Hurrell 1995). Our data suggest such relationship practically for the whole Eurasia.

No strong relationship was found between autumn numbers of Coal Tits on the Courish Spit and spring air temperatures and NAO values in large areas. Earlier we found a significant positive correlation between the mean April temperature in the study area (Kaliningrad Region) and autumn Coal Tit numbers (Markovets & Sokolov 2002). The relationship for this particular region is confirmed in this study (Fig. 9). It remains to suggest that in other parts of the range spring temperatures have no significant impact on breeding performance and subsequent irruptions in the species under study.

For the summer months (June and July), a pronounced relationship between temperatures in the Southern Urals and Irtysh areas and autumn numbers of Coal Tits on the Courish Spit was revealed. However, June temperature in the Baltic area was negatively related to Coal Tit numbers. July temperature in the Southern Urals, Ob and Irtysh areas, and in Central Europe and Southern Baltic it is positively correlated with autumn Coal Tit numbers on the Courish Spit. Irruptions occur there in the years when temperatures are high in June and July in the Southern Urals and Irtysh area. Golovatin (2002) reports that June and July are the most important months for the abundance and activity of insects in the lower Ob. Invertebrate food is an important factor for the survival of juveniles in nests and during the postfledging period. It is not unlikely that in more southern areas (Irtysh and Tobol basins) summer temperatures are most important for the survival of juvenile Coal Tits.

Autumn numbers of Coal Tits on the Courish Spit were significantly positively related to August air temperatures in Western and Central Europe. September temperatures showed positive relationships in Scandinavia, Eastern Siberia and Primorye (south of the Russian Far East), October temperatures - in the vast areas of Eurasia from the Baltic to Sakhalin. The higher was the temperature in these autumn months in these regions, the more Coal Tits were captured on passage on the Courish Spit. It may be assumed that, first, warm weather in autumn enhances better survival of juvenile Coal Tits participating in irruptions. Second, atmospheric circulation in years with warm autumn may encourage Coal Tits to reach our study area. The NAO index for August is positively related to air temperature in Western and Central Europe and Coal Tit numbers on autumn passage on the Courish Spit (Tab. 1, 2). August weather may indeed be important, because it is when juvenile Coal Tits start their autumn movements. Warm autumn weather in the vast areas of Eastern Europe and Siberia together with easterly winds favours Coal Tit migration towards the west and southwest.

The aforementioned considerations allow us to assume that the majority of Coal Tits captured on the Courish Spit in irruptive years do not have a Baltic origin. Most birds probably originate from the eastern populations of European Russia and possibly Western Siberia.

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