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GLOBAL CLIMATE CHANGE, BIRD MIGRATION AND BIRD STRIKE PROBLEMS

Mecislovas Zalakevicius
Institute of Ecology, Akademijos 2, LT 2600 Vilnius, Lithuania
Email: Mza@ekoi.lt

Abstract

The article analyses the dependency of different migratory processes on global climate change and the bird strike prevention problems possibly related to it. Climate change has a direct impact on the spring arrival of breeding birds and their autumnal departure. Of all the migration processes and their constituent parts, migratory take-off is the most sensitive to climate change. Birds try to take-off under particularly favourable for the flight conditions. Thus, climate change is predicted to induce certain shifts in take-off periods, influence alterations in staging areas and the formation of bird accumulations therein, and eventually condition the number of to it. Climate migration waves, periods of their occurrence, migratory distances, and the characteristics of the species' migratory course. Migration control is based on the principle of the dynamic balance between environment, i.e. climate, and the inner endogenous programme, while global climate change affects both the endogenous programme, readiness for flight by changing migration waves, and environmental conditions. Thus, bird migration control may change only the ranges of the dynamic balance, what is essential for a practical use of migration controlling mechanisms, i.e. the structure of models and the expression of formulae. Under the impact of climate change, changes in migratory state, migratory routes, migration distances and directions, places of staging and wintering, as well as migration intensity occur. These changes have a direct influence on bird strike problem management: ways of solution, concrete measures, their effectiveness, etc.

Key Words: Bird migration, Bird strike, Climate change, Forecast system, Spring arrival, Migratory take-off.

Introduction

According to the existing statistics, most collisions between birds and aircraft occur during seasonal bird migration periods and over the territories of migratory flights. Therefore, bird migration characteristics could be useful in long-term forecasting of bird migration aimed at the enhancement of flight safety in aviation. Besides, short-term forecasting of constituents of migration processes is successfully used to solve the bird strike problem in civil and military aviation. These topics were discussed in our articles at previous IBSC conferences on the applied issues. Unfortunately, bird migration processes are not stable year in year out. They are highly dynamic and are being affected by changing habitats and the weather situation not only during the migration seasons but also in different years. The purpose of this article is to present the data obtained on the dependency of different migratory processes, spring arrival, migratory take-off, spring and autumnal ***en route*** migration, migration abruption, and their characteristics, on the process of global climate change. Our investigations carried out in Lithuania are related with changes in the bird first spring arrival, patterns of migration ***en route*** and their characteristics, trends of staging and wintering grounds and concentrations, and those of bird breeding ranges (Zalakevicius, 1997, 1998, 1999, Zalakevicius & Svazas, 1997).

The problem

The impact of global climate change on birds recently has been described by many authors (Brown, 1991, Duffy, 1993, Rheinwald, 1994, Mingozzi, D'Oleire-Oltmanns, Miquet, Schuster, 1994, Kooijman, 1994, Hengeveld, 1994, Burton, 1995, Sokolov, et al., 1998, Sokolov, Payevsky, 1998, Olivier, 1998, Mineev, 1999, Sokolov et al., 1999, Peter, 1999, Berthold et al., 1999). P.Evans (1997) points out three possible scenarios of a large-scale impact of climate change on bird migration: birds may follow shifting floral belts; migrants can change their routes and become wanderers when habitats are rapidly changing in their staging areas; geographical variations of temperature and precipitation can cause desynchronization on migratory routes. For instance, on arctic breeding sites climatic conditions may become favourable much earlier in the year (or in the seasons of the year) and they may not coincide with favourable conditions in the staging concentrations of birds on migratory routes, thus delaying their arrival at breeding sites. Consequently, a decrease in the productivity of breeding areas, or even their shift, could result in. In addition to temperature, P.Evans (1997) indicates the width of ecological barriers (unfavourable areas) and the strength and direction of winds as the most important factors limiting bird migration.

Study area and methods

This article has been prepared based on combined investigations, i.e. long-term research into bird migration carried out during 1974-1999 in Lithuania and partially in the adjacent territories (Latvia, Belarus, the Baltic Sea) using different methods: radar, route counts of spring arrival in different regions, areas and habitats, diurnal visual observations from several watchpoints, moonwatching, nocturnal visual observations in the dispersed electric light of greenhouses, mist nets at night, ceilometer at night, recording of nocturnal voices of migrants, etc., and the laws established by mathematical methods on the dependency of bird migration on different climatic factors. For modelling, five species, Sky Lark, Starling, White Stork, Cuckoo, and Swallow, with different periods of spring arrival with Lithuania (120 observation stations) during the season, were selected. The arrival models of the species were worked out. For comparison, extremely different spring seasons were selected.

The data on spring arrival with Zuvintas Strict Nature Reserve (southern Lithuania) and the environs of Vilnius (east Lithuania) were collected during daily routes in the course of 30 years (1966-1995) (Ivanauskas et al., 1997). Investigations into the regularities of changes in spring arrival were carried out for short- and long-distance migrants separately having distinguished three periods of time: the overall 30-year period, the 23-year period prior to a substantially expressed global warming (1966-1988), and 7-year period under the conditions of a substantially expressed global warming (1989-1995). Long-term average arrival dates of separate species, their fluctuation ranges, dispersion, other characteristics were established. The data were included only for those species the material about which for each of the three periods made no less than 60%, and which fell into all the three periods.

The methods applied and mathematical-statistical data processing were described in several earlier publications (Zalakevicius, 1987a, 1987b, 1994, Zalakevicius et al., 1994, 1995).

The data on staging and wintering bird concentrations were collected on different Lithuanian inland, coastal, and marine waters (Zalakevicius et al., 1995, Zalakevicius, Svazas, 1997). Research on the impact of climate change on bird breeding was accomplished with 172 of 214 breeding bird species in Lithuania. Recently population rate has increased in 22 bird species and decreased in 54. Population rate is stable in 96 breeding bird species. The most precise data on the distribution and population state of the birds in the Western Palearctic, published in ***The Birds of the Western Palearctic: Concise Edition*** (vol. 1, 2, Oxford University Press; BWP: CE), were used along with the database accumulated at the Laboratory of Avian Ecology, Institute of

Ecology, Lithuania, on the distribution, abundance, and status of the birds breeding in Lithuania.

Results concerning the changes in bird spring arrival

The results obtained indicate that under the conditions of a substantially expressed global warming (1989-1995) the dates of arrival with Zuvintas Strict Nature Reserve (southern Lithuania) are becoming obviously earlier for both short- and long-distance migrants and their complexes. Under the conditions of lower temperatures (1966-1988), arrival dates used to be later than average (1966-1995). The analogous data were obtained during the research carried out in the environs of Vilnius (eastern Lithuania). Increase in temperature induces total shifts in the spring arrival of birds changing both its beginning and end. The most marked differences in the arrival dates (in between the periods “prior to a substantially expressed global warming” and “after a substantially expressed global warming”) were observed in the beginning of the arrival season. Then in the course of the season, the differences would decrease. This is more typical of short-distance migrants their arrival dates towards the end of the season becoming more similar both in the season itself and between species. For long-distance migrants, this difference is less significant both in its magnificence and in the rate of trends. Besides, for long-distance migrants (Table 2) the difference does not change throughout the whole season, while for short-distance migrants (Table 1) it disappears at the end of the season.

Comparing short- and long-distance migrants (their complexes) for the whole 30-year-period we defined that as a rule short-distance migrant species are the first to arrive with Zuvintas (Table 1; on 62nd-73rd day), then the arrival of long-distance migrants takes place (Table 2; from 75th day). At the end of the season, short-distance migrants are the first to finish their arrival (Table 1, 124th day), long-distance migrants being left behind (Table 2; 134th day).

The study of spring arrival in Lithuania, as well as Central and Eastern Europe, shows that the course of arrival of both the five model species, Skylark, Starling, White Stork, Swallow, and Cuckoo, distribute in the arrival season in a certain succession, and the whole species complex directly depend on the rise in temperature (Zalakevicius et al., 1995). In early springs, bird arrival takes place earlier than in late springs. It is related to the abundance of available food, which directly depends on air temperature. The course of spring air temperature defines arrival periods and the rapidity of territory occupation, which is slightly lower in case of an early spring, for both early and late arrivals. Hence, the climate change is markedly changing the periods of bird arrival, timing of their accumulations on the territories of spring migration.

Table 1. Characteristics of the first spring arrival of short-distance migrants with Zuvintas Strict Nature Reserve (month, day, for the three periods: prior to global warming, overall, under global warming conditions)

Bird species	Results					
	1966-1988		1966-1995		1989-1995	
	Average	±SE	Average	±SE	Average	±SE
Mallard	3.08	3.6	3.03	3.7	2.09	8.5
Starling	3.10	1.5	3.06	2.0	2.18	4.5
Skylark	3.10	2.0	3.07	1.9	2.26	3.7
Lapwing	3.11	1.6	3.08	2.0	2.24	4.9
Bean Goose	3.17	1.5	3.14	1.7	3.03	3.1
Greylag Goose	3.18	1.7	3.12	2.4	2.24	4.4
Bittern	3.18	1.7	3.17	1.7	3.14	4.4
Common Gull	3.18	3.0	3.14	2.9	2.28	5.3
Goldeneye	3.19	1.8	3.13	2.9	2.22	7.6
Reed Bunting	3.19	1.6	3.14	1.9	3.03	3.1
Chaffinch	3.21	1.9	3.19	1.9	3.10	4.2
Linnet	3.24	1.8	3.20	1.8	3.12	2.8
Coot	3.24	1.7	3.20	2.1	3.05	3.9
Wigeon	3.25	1.8	3.21	2.2	3.05	3.5
Common Gull	3.26	1.8	3.20	4.6	3.11	14.8
Pochard	3.27	1.5	3.22	2.1	3.08	4.4
Wood pigeon	3.27	2.4	3.23	2.2	3.12	2.6
Teal	3.27	1.9	3.24	1.7	3.19	3.1
Redshank	3.27	1.0	3.25	1.3	3.18	3.2
White-fronted Goose	3.27	2.7	3.20	2.6	3.07	3.3
Pintail	3.28	2.0	3.28	2.6	2.27	8.4
Smew	3.28	1.8	3.22	2.3	3.06	3.3
Snipe	3.28	1.8	3.25	1.8	3.16	3.3
Tufted Duck	3.29	1.6	3.24	2.4	3.08	5.4
Black-tailed Godwit	3.30	0.8	3.29	0.9	3.26	2.9
Robin	3.31	1.4	3.28	1.3	3.22	0.0
Great Crested Grebe	4.03	2.3	4.01	1.9	3.27	2.5
Curlew	4.06	2.8	4.03	2.4	3.23	3.4
Cormorant	4.08	4.9	4.09	3.7	4.11	5.5
Penduline Tit	4.13	4.4	4.13	3.3	4.15	4.3
Ruff	4.22	2.1	4.21	1.7	4.21	3.4
Whinchat	4.28	1.3	4.27	1.0	4.25	1.1
Little Gull	5.03	1.1	5.04	1.0	5.06	2.3

Table 2. Characteristics of the first spring arrival of long-distance migrants with Zuvintas Strict Nature Reserve (month, day, for the three periods: prior to global warming, overall, under global warming conditions)

Bird species	Results					
	1966-1988		1966-1995		1989-1995	
	Average	±SE	Average	±SE	Average	±SE
Grey Heron	3.20	1.4	3.16	1.8	3.05	1.3
Meadow Pipit	3.23	1.5	3.19	1.8	3.11	1.3
Garganey	3.25	1.2	3.22	1.5	3.16	1.7
White Wagtail	3.26	0.8	3.25	0.9	3.22	0.8
White Stork	3.27	1.0	3.26	1.0	3.22	0.8
Marsh Harrier	3.27	1.1	3.24	1.7	3.13	2.0
Song Thrush	3.28	1.0	3.22	1.6	3.12	0.9
Crane	3.29	1.6	3.24	2.3	3.08	1.6
Willow Warbler	4.15	1.4	4.16	1.4	4.20	1.0
Swallow	4.19	1.1	4.18	1.1	4.13	0.9
Blue-headed Wagtail	4.21	0.9	4.20	0.8	4.18	0.5
Savi's Warbler	4.21	1.2	4.20	1.2	4.15	0.8
Common Tern	4.22	0.9	4.21	1.3	4.15	1.7
Spotted Crake	4.23	2.0	4.22	1.8	4.20	1.2
Sedge Warbler	4.28	0.9	4.26	1.0	4.23	0.9
Black Tern	4.29	0.9	4.27	2.2	4.21	4.1
Cuckoo	5.01	1.4	4.30	1.3	4.26	0.3
House Martin	5.01	1.0	4.30	1.0	4.26	0.5
Great Reed Warbler	5.02	0.7	5.02	0.6	5.03	0.5
Sand Martin	5.07	1.7	5.04	1.7	4.28	1.0
White-winged Black Tern	5.09	0.8	5.11	1.5	5.16	2.4
Golden Oriole	5.11	1.1	5.09	1.2	5.05	1.1
Swift	5.14	1.1	5.14	0.9	5.14	0.3

Changes in bird migration take-offs

Of all migration processes and its constituent parts, the most sensitive to climate change is migratory take-off. We defined that birds try to take off under particularly favourable for the flight conditions (Fig. 1). It helps them to avoid extreme flight conditions in a great part of their migratory passage (Zalakevicius, 1990a, 1993, Zalakevicius et al, 1995). Preparation for take-off in the places of concentrations takes the whole 24-h period. Under the first appearance of favourable conditions, birds usually do not take-off but wait for 24 hours for the weather conditions still to improve, and then start their migratory flight. In the course of evolution, birds have gained the ability to be susceptible to the slightest fluctuations in the weather parameters to use this ability during migratory flights between breeding grounds and winter quarters.

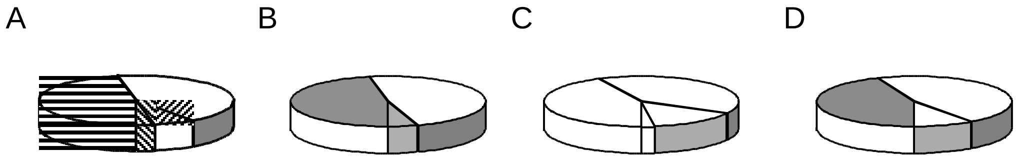
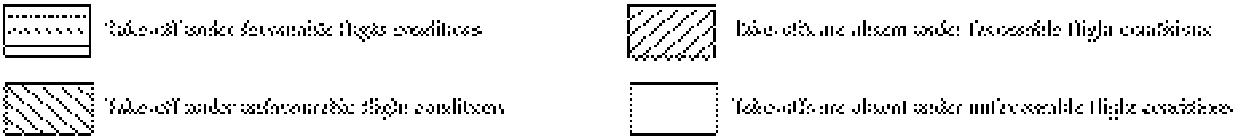


Fig.1 . Bird take-offs under different conditions of the synoptical weather situation
A: spring migration on the continental part, B: spring migration on the coastal zone of the Baltic Sea, C: autumnal migration on the continental part, D: autumnal migration on the coastal zone of the Baltic Sea



Based on our data, we may confirm that for migratory take-off to occur the whole complex of favourable weather parameters is necessary: rise or fall in temperature and a certain speed of this change, increase in barometric pressure, little cloudiness, weak tail winds, absence of precipitation. Information about separate bird species and take-off specificity in environmental conditions is very essential, too.

The analysis of the bird autumnal migratory take-off revealed some bird species to take off at a low day air temperature (geese – on average at 4.92±0.53^{o}C, Skylarks – 5.74±1.41^{o}C), and others at somewhat higher temperature (thrushes, Woodcocks, Long-eared Owls at 6.56±0.69-6.74±1.01, Goosanders – 7.46±0.98^{o}C, Robins – 8.31±0.42^{o}C, Wood Pigeons – 7.25±0.83-8.53±1.30^{o}C). Under high pressure were registered take-offs of geese, Goosanders, thrushes, Robins, Skylarks, only. Almost all the take-offs of geese were registered under clear or partly clouded sky, while as many as 54.1% of the take-offs of Goosanders occurred under solid overcast (Zalakevicius, 1990a, 1993, Zalakevicius et al., 1995).

Considerable differences were observed as far as cloud height was concerned. The majority of species would take off under low clouds (up to 0.5 km), while geese and thrushes – always under the cloud height of over 0.5 km.
Geese, thrushes, Robins would always take-off with tailwinds and following-side winds, while as much as one third of the Goosanders take-offs were observed under opposing, opposing-side winds. The take off of most the

species occurred under the wind velocity of less than 3 m/s, however Wood Pigeons were observed to take off under even 4.5±0.89 m/s. Geese, Woodcocks, thrushes, and Robins are distinguished for their sensitivity to visibility and rain (Zalakevicius, 1990a, 1993, Zalakevicius et al., 1995). This specificity is more tangible and important in migration initiation for the first spring arrival and take-off. Thus, climate change is predicted to induce certain shifts in take-off periods, influence alterations in staging areas and the formation of bird accumulations therein, and eventually condition the number of migration waves, their occurrence periods, migratory distances, and characteristics of the species' migratory course.

Changes in bird migration *en route*

Based on our data on temperate latitudes, the main parameters acting on the manifestation of the endogenous programme in nature are: wind direction and velocity, air temperature, speed of its change and trends, different constituent parts of cloudiness, and visibility. All of them have a concrete biological sense: energy saving during the flight, optimum aerodynamic conditions, abundance of available food to supply energy deposits, optimum or at least minimum conditions for orientation (Zalakevicius, 1990). They are of a paramount importance for survival. Together with the main weather parameters, migration intensity ***en route*** is conditioned by a series of other weather parameters influencing the flight at the same time (in a complex way): barometric pressure, speed of its change and trends, relative humidity, good, i.e. anticyclonic, weather. Weather factors are closely interrelated and often act together. The analysis of the factors showed the parameters, defined as the main, often to be related to many other weather variables and, giving the best explanation of them, to be the main or crucial in models. Their changes often encompass the change in the meanings of many other weather variables. It may be illustrated by a cloud type – one of the main variables determining the intensity of the spring and autumnal migration. A great influence of the cloud type on the course of migration may be explained by its close relationship to other weather variables, which at the same time are well represented by one cloud type. Thus, using univariate mathematical statistics to study the data on nocturnal spring migration in the coastal zone of the Baltic Sea, we defined the cloud type to show a high correlation with the total cloud amount (correlation coefficient r = 0.6909, low cloud amount (r = 0.6659), cloud altitude (r = 0.7285), rain amount (r = 0.4092), index of synoptical weather situation (r = -0.4625), surface barometric pressure (r = -0.336), relative humidity (r = 0.3257). Investigations carried out with the help of the factor analysis based on the above material including 20 weather variables (without migration intensity) showed the second distinguished factor to have the greatest describing power (17.956%) and to join the following weather variables with the greatest factoral loads: cloud type (r = 0.8553), cloud amount (r = 0.7812), low cloud amount (r = 0.7812), cloud altitude (r = 7788), rain amount (r = 0.5038), index of synoptical weather situation (r = 0.5743), barometric pressure (r = -0.3369), relative humidity (r = 0.312).

This confirms any changes in weather parameters to have a considerable impact on the timing of migration volume and different species, number and length of waves, timing and areas of stop-over for feeding and resting on migration.

Changes in bird migration control

Studies of bird migration by implementing different methods enabled a description of visible and invisible migration: its nature, characteristics, scope, origin of single layers and place in the migratory process. The modelling of the general course of the upper and lower migration layer and intensity dynamics of single bird species promoted development of a new theory of migration control. It provides that the occurrence and course of the migration wave is being controlled by the dynamic balance between the endogenous mechanism initiating the wave (and completely manifesting itself in the weather ideal for flight) and environmental conditions (acting on the endogenous program and the flight in nature), what conditions the occurrence and course of migration and the migratory behaviour of birds (Zalakevicius, 1987a, 1990b, Zalakevicius et al., 1995). Arisen as an adaptation to climate changes, the whole migratory movement adapts to seasonal weather. Migration control is based on the principle of the dynamic balance between environment, i.e. climate, and the inner endogenous programme, while global climate change affects both the endogenous programme, readiness for flight by changing migration waves, and environmental conditions. Thus, bird migration control may change only the ranges of the dynamic balance, what is essential for a practical use of migration controlling mechanisms, i.e. the structure of models and the expression of formulae. Under the impact of climate change, changes in migratory state, migratory routes, migration distances and directions, places of staging and wintering, as well as migration intensity occur. These changes have a direct influence on bird strike problem management: ways of solution, concrete measures, their effectiveness, etc.

Changes in bird wintering and staging, migratory-resident state

According to our investigations marked changes in the populations of wintering, staging and migrating waterfowl have occurred throughout recent decades in Lithuania, what is largely due to global warming (Zalakevicius, Svazas, 1997). This phenomenon may be of a direct interest in solving the bird strike problem.

Recently, over 10 large waterfowl wintering grounds have formed in Lithuania, holding annually up to 150,000 waterfowl. The numbers of separate wintering species are growing together with a marked increase in the number of resident individuals within populations. A very good example of such a rapid increase in the numbers is observed in the population of wintering Mallards. In the 1940s, Lithuania was annually counting a few thousand wintering Mallards, while currently the annual estimate of the wintering population is as large as 35,000 Mallards. Presently the major part of the Lithuanian population of Mallards is formed of the resident or partly migrant birds wintering close to their breeding grounds.

Due to this process, migratory routes have shortened for many wintering species. Consequently, new additional staging sites, new scenarios of bird migration could be observed. Previously, the majority of the Mallards breeding in Lithuania were detected in England and France, whereas currently most records come from Poland and the adjacent countries (Zalakevicius, Svazas, 1997).

The selection of wintering grounds by Mute Swans has also changed. Formely, the majority of the Mute Swans breeding in Lithuania were observed wintering in the Netherlands, Germany, France, and Denmark, while nowadays the main bulk of the birds spend winters in the Baltic Region (the German and Polish seacoast; Zalakevicius, Svazas, 1997). Every year an increasing number of Mute Swans are wintering in Lithuania. Therefore, the length of the migratory route has nearly halved.

Distinct changes were also defined in the main wintering grounds of the waterfowl populations breeding in the tundra zone of the Western Palearctic and in European seas. Currently, a constant increase in the majority of the sea duck species wintering on the Lithuanian Baltic coast and Curonian Lagoon is observed (Zalakevicius, Svazas, 1997).

In 1988-1999, in Lithuania, almost exponential growth rate of the population of wintering Goosanders was registered. The change of the wintering grounds of the regional population of Smews was observed too. In 1977-1983, up to 90% of the total Northwest European population would winter in the Netherlands, while presently as many as 86% of it are concentrated on some East Baltic wintering grounds: Northeast Germany, Poland, Lithuania (Zalakevicius, Svazas, 1997). Similar to Goosanders, the wintering population of Smews has shifted eastwards by 5 degrees.

Considerable changes were revealed in the wintering grounds of Velvet Scoters and Long-tailed Ducks. In the beginning of the 1970s, their main wintering grounds were known in the southern part of the Baltic Sea, however lately the major part of their populations winter by the eastern coasts of the Baltic Sea (Riga Gulf, Lithuanian and Gotland coastal areas). Thus, wintering populations of these species have shifted northwards by 800 km (Zalakevicius, Svazas, 1997).

Definite changes in the section of the migratory stop-over areas of the waterfowl populations in Northwest Europe are noteworthy too. In the 1960-1970s, the stop-over concentrations of migrating Whooper Swans and Bewick's Swans were mainly recorded in the coastal zones of Denmark, Sweden, and Germany, whereas in present – near the coast of Lithuania. The main stop-over areas have shifted 800 km northwards. In the 1970s, Bewick's Swans were rare visitors in Lithuania, while recently up to 18% of the total European population have chosen Curonian Lagoon for their rest during the spring and autumnal migrations (Zalakevicius, Svazas, 1997).

As for the White-fronted Geese, 10 years ago in Lithuania they scarcely made 20-30% of all the migrating geese, whereas now – some 80-90%. Stop-over areas of an international importance have formed. That is probably due to the shift of the wintering grounds of this species from Hungary, Austria, and Slovakia to the Netherlands. Its migratory flyway has also changed to run along Curonian Lagoon now (Zalakevicius, Svazas, 1997).

To summarise a statement could be made that the investigations carried out by the Institute of Ecology, Lithuania, revealed marked shifts in wintering ranges and migratory flyways of many waterfowl populations. Due to the sustained warming of winter seasons, the majority of species have shifted east- and northwards; the main stop-over areas of migrating populations have changed; the number of resident birds in different populations is rapidly increasing, the migratory distances have reduced. The above problems should find place in the bird strike prevention: long-term forecast of periods, concentrations, flyways, and migration routes.

Changes in bird breeding distribution areas – shifts of ranges

Our research indicates global climate change to have a noticeable impact not only on bird spring arrival, migratory take-off and ***en route*** flight, staging or wintering features and characteristics, and residence-migration state, but also on the status of breeding, state of populations, stability or shift of ranges. The abundance of populations in a particular territory depends on conditions favourable for the species. The most favourable conditions are in the central part of the distribution area, while unfavourable in the periphery. Based on our data, the impact of climate change is unequal in different parts of a population's distribution area. Due to the climate warming, environmental conditions have become favourable in the N-NE-E part of the range and unfavourable in the W-SW-S part. Under the influence of the changing conditions, the Baltic States are facing the shift of species distribution areas (including northern and southern boundaries) northeastwards. The populations of southern bird species are expanding and the abundance of northern bird populations is diminishing in the region. The process taking place in certain species, the increasing or decreasing populations consequently influence the migration volume in particular (southern, southeastern) areas. Many examples of this kind could be picked out from scientific literature. The shift of the ranges northeastwards and the increasing population density in the territories northeast of Lithuania enlarge the numbers of the autumnal migrants registered in Lithuania. Changes in the migration volumes of the species of a special interest could be forecast in various regions with practical application to the bird strike prevention.

Conclusion

Though the global warming impact on wildlife has so far been insufficiently investigated, the effect of climate change is evident. One of its indications is the migratory-resident state of migrants, being developed in the course of evolution as a response to periodical global processes on the Earth global warming being the most distinguished among them in recent years. Changes in wildlife affect various processes bringing about new problems in different spheres, including flight safety in aviation.

The forecast of migrant arrival phenology confirms the importance of external factors in determining the manifestation of the endogenous basis of migration regulation. These factors shall be considered on actual forecasting the beginning of the passage. The impact of climate change on this process is evident. Species specificity markedly varies as far as arrival is concerned and depends on the particular selective factors affecting the species. This specificity is protecting the species from impacts of unfavourable environmental conditions. Controlling mechanisms, having a long history of development, are co-ordinated with the concrete changing environment. Climate change is markedly changing the periods of bird arrival, timing of accumulations on spring migration.

The studied connection between the course of various migration stages in separate bird species and weather variables as well as their alterations was established to have both common and specific features. Hence, spring arrival, take-off, and the course of migration of all the bird species studied occurred at certain air temperatures (increasing temperature in spring and dropping temperature in autumn), under high barometric pressure still increasing, weak tailwinds, clear sky without rain, good visibility conditions. Furthermore, birds were ascertained to leave their starting areas only on the second day (or night) after a temperature increase (in spring) or decrease (in autumn). The increase/decrease was the greatest on the day (or night) of the take-off. Moreover, mass character of the take-off in the concentration areas of birds and the density of the migration to follow depended on the level of these trends. The take-off occurred at similar regularities of relative humidity and barometric pressure. The take-off was observed only on the second day of improved travelling conditions. This is a special adaptation enabling birds to choose the most optimal conditions and time for their flight. All this reduces the degree of risk of encountering unfavourable, unexpected, and sometimes fatal conditions. This is an explanation or an answer why of all the migration processes the migratory take-off is the most sensitive to climate change.

Shortened migration distances between breeding and wintering sites have been recently confirmed by ringing recovery data of various bird species ringed in Lithuania. Global warming is predicted to cause a shortened migratory route of the birds breeding in Lithuania, their winter quarters coming nearer. A direct anthropogenic effect is also important: change of habitats, use of protective measures, etc. Unfortunately, the impact of global climate warming on bird populations becomes more important in comparison to anthropogenic loading. Sometimes these two factors act as a complex impact.

The process has both theoretical and practical value. There have been no investigations yet into how the mechanisms controlling bird migration and the endogeneous programme forcing birds to migrate may change, and how the relationship with environmental conditions may alter. The formation of new winter quarters will influence economic activities, and new environmental and other problems, in civil and military aviation first, will emerge. Due to the sustained warming of winter seasons, the majority of species have shifted east- and northwards; the main stop-over areas of migrating populations have changed; the number of resident birds in different populations is rapidly increasing, the migratory distances have diminished. All these problems should find place in the bird strike prevention: the long-term forecast of periods, concentrations, flyways, routes of migration.

An analysis of the dates of the first captures and the mean dates of spring migration in 33 passerine species through Curonian Spit revealed that the earlier a species migrates, the greater is the inter-annual variation in the timing of the passage (Sokolov et al., 1998). According to L.V.Sokolov et al. (1998), a comparison of the spring migration timing in 20 migrant species with mean monthly temperatures showed a significant relationship between the mean arrival date and mean temperature in 12 species that migrate primarily in April and May. Higher temperatures were associated with earlier migration.

Authors point out that over the 20th century long-term trends in the timing of spring bird migration occurred, especially in passerines. According to the authors, these trends are caused primarily by climatic fluctuations in the Northern Hemisphere. They affirm that warming in the 1930s and 1940s and then in the 1960s and 1980s has led to significant shifts in the spring migration timing towards earlier dates. Conversely, colder periods during the 1950s, 1970s and possibly 1990s, have caused a later passage. The authors also note that climate change has influenced the migration of the species wintering both within Europe and in Africa, i.e. short- and long-distance migrants. In another article, L.V. Sokolov et al. (1999) present data on autumn migration. The analysis of the mean date of autumnal migration in juveniles in 26 passerine species over 40 years (1959-1998) revealed considerable inter-annual variation in the majority of species. Authors conclude that the main reason of long-term variation of the timing of autumn passage in passerines in the study area are long-term climate fluctuations in Europe in the 20th century. This has caused a respective shift in the autumn migration timing in a number of species. Colder periods in the 1970s and to some extent in the 1990s, to the contrary, have resulted in a later migration in some passerines. V. Payevsky (1999) states that “factors causing population change act over large areas, influencing breeding areas, migratory routes, and winter quarters. Global climate change may be such a factor”. It was clearly demonstrated on the bird species breeding in Lithuania (Zalakevicius, 1998, 1999). In some parts of the continent, inter-annual fluctuation of spring and summer temperatures may play a role. In the paper, data were presented on changes in bird distribution areas – recently registered shifts of ranges. This is related with the abundance and trends of populations. Based on our data, the impact of global climate change on habitats and food resources is better expressed on land and for terrestrial and wetland bird species (Zalakevicius, 1999). Meanwhile, habitats of hydroecosystems are not so strictly influenced by global warming. The impact of climate change on the state of populations and shift of ranges northwards-northeastwards can also be found on investigating material on bird ringing and registering the number of ringed birds. Such an interesting indirect evidence of the impact of global climate change on bird populations can be illustrated by several examples. Wozniak (1997), considering the numbers of birds caught in autumn at ornithological stations of Western and Central Europe, indicated that the Black Redstart (***Phoenicurus ochruros***) population was increasing in the period of 1961-1996. Our analysis revealed the northeastern edge of the entire range of this species to adjoin Latvia and Belarus (BWP: CE). If conditions for the species in the northeastern periphery of the range are getting better under the influence of climate warming, they become equal to the species optimum and the range moves northeastwards. An increasing number of birds, which fly past the ringing stations of Poland and Germany during their autumn migrations southwestwards, hatch in the areas northeast of the ringing stations. All these facts indicate that the abundance of the population is growing to the northeast of the stations and the range is expanding in that direction.

Another analogous example is the data on the caught ringed tits collected by J.Baumanis, A. Celmins (1993). These authors provide that the numbers of Crested (***Parus cristatus***), Blue (***Parus caeruleus***) and Willow (***Parus montanus***) Tits have been increasing during their autumn migrations since 1967. The analysis of the ranges of these species presented in BWP: CE shows that Latvia is in the center of these ranges or closer to their northern periphery (in the Blue Tit's case). The increase in the tit populations and expansion of their ranges to the north-northeast of Latvia may be the reason for the growth of the number of the species in Latvia during their autumn migrations. It is evident that these bird species are increasingly facing optimal conditions in the north and northeast of Latvia.

Consequently, a conclusion could be drawn that climate change is inducing certain shifts in the bird spring arrival and take-off periods, influencing ***en route*** migration and alterations in staging areas and the formation of bird accumulations therein, and eventually conditioning the number of migration waves, periods of their occurrence, and the characteristics of the species' migratory course. Climate change is altering the ranges of the dynamic balance, what is essential for a practical use of the mechanisms controlling migration, i.e. the structure of models and the expression of formulae. Thus, under the impact of climate change, changes in migratory state, migratory routes, migration distances and directions, places of staging and wintering, as well as migration intensity occur. Knowledge of these changes has a direct influence on the success of the bird strike problem management: ways of solution, applicability of concrete measures, their effectiveness, etc. Existing gaps in details of the impact of global climate change on bird migration characteristics require additional research.

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