Large-scale modern climate change and reactions of steppe birds of Inner Asia

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Abstract. On the basis of many years of work by ornithologists covering the entire second half of the past and the beginning of the current century, the features of the dynamics of the bird fauna of Inner Asia as a result of climate warming are considered. The central position of Eastern Siberia caused its stronger warming, which makes it possible to consider in detail various aspects of this process. Severe droughts, followed by long dry periods, observed in the arid regions of Central Asia in the second half of the 20th century, caused massive migrations of birds to the north. Strong changes in habitats were found in birds using intrazonal wetlands ecosystems for nesting. Native steppe and desert birds inhabited areas within their natural zone. They are characterized by occasional flights to the northern boundaries of their ranges towards the end of the second half of the study period. As a result of mass evictions, the diversity of birds in Eastern Siberia increased by 22.6% (110 species), but their abundance remained almost at the initial level. At present, the number of coastal birds in the south of Eastern Siberia, as well as in Central Asia, has greatly decreased, as a result of a shift in the optimum range to the north.

1. Introduction

The materials of ornithological research in Eastern Siberia for the first period of rather intensive work (mid 19th – mid 20th centuries) were summarized by T.N. Gagina [1]. It should be noted that this review used materials from earlier studies, but they were not enough to characterize this huge region [2-4]. By the middle of the last century, Eastern Siberia had been surveyed quite fully, and special reports were published for its individual regions. This allows us to consider the large generalization made as relevant for further research. It gives a fairly complete picture of the bird fauna of the past period and allows you to use it for further comparisons in subsequent studies. At the same time, it should be pointed out that this is the initial period of climate warming, in comparison with the previous Little Ice Age (early-mid-14th - mid-19th centuries). Therefore, the general fauna of birds at that time was depleted, although the abundance of waterfowl in temperate latitudes was very high.

The modern bird fauna of Eastern Siberia (the second half of the 20th and the beginning of the 21st centuries) was formed under more favorable conditions. Since the end of the last century, a very strong warming has been observed, which has caused significant changes in the bird fauna of this region. By this time, the bird fauna of Eastern Siberia had been studied quite fully. This is especially typical for the southern regions and the Baikal region. However, in the subsequent (restructuring) the intensity of ornithological research has decreased markedly. At the same time, the system of nature reserves and national parks created by this time provided the receipt of materials necessary for comparing the bird fauna of these long and peculiar periods. At present, several large reports of birds have been published, which make it possible to assess the ongoing changes in a sufficiently qualitative way [5-17]. Along
with this, large surveys of the bird fauna of territories adjacent to Russia have appeared [18-21]. This allows a more complete and correct assessment of the changes taking place in the bird fauna of Eastern Siberia.

Climate warming has led to significant changes in the species composition of birds in Eastern Siberia [12-15, 17, 22-24]. However, the process of changing their fauna was quite long and included several characteristic stages. This required a special analysis of the collected materials. The dynamics of the faunistic composition of primordial steppe bird species is of particular interest. Droughts and dry periods, first of all, covered Central Asia, and birds were moved from arid territories. Therefore, the reactions of birds in these regions are of greatest interest. In this work, the processes that characterize the dynamics of the species composition of migrating birds and the formation of the modern avifauna of Eastern Siberia are specially considered.

2. Materials and Methods

Our own work covered the whole of Eastern Siberia, but the most intensive and detailed studies were carried out in the Baikal region and in the basin of Lake Baikal. The start of work coincided with the first large evictions of birds from Central Asia and continues to this day (1963-2021), Eastern Siberia, mainly a mountainous country with a large number of plateaus. In the south of this region, vast areas of zonal steppes pinch out, entering here from the territory of Mongolia and northern China. The central part of Eastern Siberia is occupied by the vast Sayano-Baikal Stanovoye Upland, which includes the most highly elevated and highly fragmented mountain ranges. Their height reaches 2500-3500 m above sea level, the elevation of the bottom of the basins is 455-1400 m. North and south of the Sayano-Baikal Stanovoy Upland, the heights of the plateaus are from 500 to 1800 m.

The climate of this territory, with the exception of the Baikal Basin, is moderately continental and sharply continental, but in the deep basins it is ultra-continental. The western transport of air masses predominates, with little moisture supply. Inland water bodies do not have a noticeable effect on the total reserves of atmospheric moisture. The river network of the region belongs to the basins of the three largest rivers of Siberia: Yenisei, Lena and Amur. It differs, with the exception of the Uldza-Torey Basin, in very high density. However, this territory is distinguished by a small lakes with a sharp predominance of small lakes, mainly of thermokarst origin, as well as lakes derived from the river bed.

Special long-term observations were carried out at three stations located in different regions of Eastern Siberia. The longest special studies were carried out on the Barluksko-Sayan section of the middle reaches of the Oka river (over 20 years) and in the Selenga river delta (continuously for 10 years, and then periodic observations for 20 years), at the mouth of the Irkut river (five years old). In addition, expeditionary research was widely used using various types of transport and methods of observation and selection of field material. The entire territory of Eastern Siberia was covered by such surveys. The work used generally accepted research methods, adapted to local conditions [5-8, 10-14, 23-24].

The analysis is based on the materials of faunistic works collected in previous periods of research. They were compared with modern materials and thus the differences in the species composition of birds in specific areas were revealed. To identify new species, photographs of amateur bird watchers were widely used, the number of which has increased significantly in the region. Additional analysis was carried out for each new species recorded. The conditions under which it was discovered and the possibility of its appearance here in this period were determined. The generalized data for fairly large areas with approximately the same physical and geographical conditions were compared with the materials of T.N. Gagina [1], obtained during the first period of research (for specific ornithological areas). On the basis of such comparisons, the current composition of birds in ornithological areas and its differences in different periods of research were clarified. On the basis of these data, the modern faunistic composition of birds in Eastern Siberia was determined and differences in the composition of the bird fauna for the first and second periods of the study of this region were revealed.
3. Results

3.1. Features of the development of the climatic situation in the Northern Hemisphere of the Earth

Modern studies of climate dynamics confirm that its changes are associated with solar activity. Its increase at the beginning of the 20th century (1910-1940) coincides with the general increase in the NAO values. This time is characterized by a change in latitudinal atmospheric transport to meridional transport, as well as warming and melting of ice in high latitudes [25-26]. The second phase of warming (1980-2000) was also accompanied by the same processes, more pronounced in the Pacific Ocean sector of the Arctic [25-26]. However, in the middle of the general period of climate warming (1940–1976), its cooling developed in the Arctic. The melting of sea ice has led to a very strong desalination of the ocean in the northern branch of the Gulf Stream and a noticeable change in water circulation in the North Atlantic. Here, vertical convection of oceanic water flows developed, and the region of formation of warm deep waters noticeably shifted to the south [25-26]. This led to a significant change in climatic conditions in the coastal regions of the northern and temperate latitudes of Eurasia and America.

The development of a stronger meridional atmospheric transfer in the North Atlantic coincided with an increase in droughts, covering very large areas in Africa, Anterior and Central Asia (1958-1964). Subsequently, the same processes began to be noted in the Pacific sector [25-26] and the change from latitudinal air mass transfer to meridional transport led to the development of very severe droughts in Mongolia and Eastern China (1968-1978) [27]. Undoubtedly, these processes are associated with a weakening of the zonal atmospheric circulation, due to which the temperature of adjacent regions is leveled. As a result, there was a noticeable increase in the warming up of the central regions of Asia [12-13], where the largest droughts for the 20th century developed and the frequency of their recurrence increased [27]. The area of contact of air masses of temperate latitudes on the periphery of the southwest direction, characteristic of this region and the East Asian monsoon, shifted to the north, and in the area of ordinary contacts, a very strong weakening of the general atmospheric circulation was observed [28]. The result of a change in the main directions of atmospheric circulation is the formation within Inner Asia of a vast, very strongly warmed up region, which almost completely includes Eastern Siberia.

The above processes were characterized by significant spatio-temporal and seasonal heterogeneity [16, 25-33], due to the high complexity of the underlying Earth's surface, especially pronounced in the mountainous regions of Asia. The area of conjugation of air masses of these directions - the Siberian frontal zone went far to the north (South Yakutia) and the frequency of contacts of the Arctic air masses with the eastern monsoons increased. At the same time, the instability of the Siberian anticyclone has greatly increased. He began very often to move from Yakutia to the border of Mongolia and China, capturing large mountain systems in the south of Buryatia, Transbaikalia and the Khabarovsk Territory. In this regard, cold air masses coming from the north began, flowing around the anticyclone, not to enter Siberia, but to Canada and Alaska, where frosts intensified to -30 °C. Similar processes are observed in the North Atlantic, which causes snowfall on the islands of the Mediterranean Sea and in Africa, as well as on the Atlantic coast of North America.

The observed changes in the circulation of air masses, leading to dramatic climate changes, strongly affect the bird fauna of the Central regions of Asia. The development of large and prolonged droughts, as well as the increasing frequency of their repetitions in its southern regions, caused a significant outflow of birds to the northern regions, primarily to the territory of Eastern Siberia. Inner Asia is characterized by the formation of very long (several tens of years) dry periods, combined with shorter, but very strong, extensive and rather long (from 5 to 10 years) droughts [16, 25-28, 30-32].

3.2. Dynamics of the climatic situation in Eastern Siberia

Eastern Siberia, in comparison with many other regions of the Northern Hemisphere, is characterized by a stronger climate warming. Here it is expressed more than twice as much - 1.9°C / 100 years (from 1.5°C to 2.2°C / 100 years) than the average throughout the Northern Hemisphere of the Earth - 0.7°C
The general level of warming in the river basin cupid increases from east to west. For 1891-2004 in Khabarovsk the warming was 1.1°C / 100 years, in Chita - 1.7°C / 100 years, and on the lake Baikal 1.9°C / 100 years [12, 16, 33]. Obviously, the dynamics of the surface air temperature in the eastern (coastal) regions of Russia is significantly influenced by the Pacific monsoons, which reduce the level of warming in the coastal regions. The climate also changes from south to north. The highest level of warming was recorded in the lowland regions of Mongolia and China adjacent to Russia: 2.2°C / 59 years (1951-2009) [16, 28, 32]. In mountainous regions, it changes from 1.9°C / 100 years in the south [12, 26, 33] to 1.0-1.5°C / 59 years in the north of the Baikal region [24, 32], i.e. this process is much less pronounced here.

In the vast territory of Eastern Siberia, in the modern period, climate changes occur quite synchronously. Most likely, this is what determines the specificity of the migration of birds to the lake Baikal and further north. The position of the lake basin Baikal, located in fact in the center of North Asia, makes it possible to well track the overall dynamics of the ranges of many bird species. The data collected here make it possible to obtain a complete and reliable picture of the characteristics of the reaction of birds of various taxonomic groups and natural zones to changes in the ecosystems of vast territories [1, 5-11, 14-15, 17-21, 24]. In some areas, different directions and strengths of climatic changes can be observed. On average, in the basin of the lake Baikal is characterized by warming in winter and early spring [33]. At the same time, in the Barguzin Basin, warming is much less pronounced, on average, only by 1.0°C, and on the northeastern coast of Lake Baikal it is expressed in the spring and summer months [13, 24]. In this case, it should be borne in mind that the methodological approaches to the study of climatic changes by different authors are somewhat different. In particular, the joint influence of temperature and humidity was studied on the northeastern coast of Lake Baikal. In general, the warming of the climate in Eastern Siberia was much more pronounced than in the adjacent territories. Therefore, it was here that it was possible to obtain the most complete and reliable picture of the dynamics of the bird population under the influence of strong climatic changes.

However, the key moment that caused the development of the trend towards the eviction of birds turned out to be strong, extensive and prolonged droughts that began in Mongolia and China in the late 40s of the last century. A critical situation developed in the mid 70s of the XX century. At this time (1975-77), a severe drought was observed in all regions of Northeast China. Its development peaked in 1977 - it covered the western regions of Mongolia, the southern regions of the Baikal region and almost all of China, with the adjacent regions of Eastern Mongolia. The next year (1978), a very severe drought was observed in all western regions of Mongolia [31]. According to experts, the probability of recurrence of such droughts is once every 100-600 years [27].
3.3 The first stage of the eviction of birds from Central Asia
Departures of birds from Central Asia began to be in the late 40s and early 50s of the XX century from the territory of Mongolia and China observed [11-14, 23]. They coincided in time with the beginning of the formation of large and extensive droughts here [27]. During this period, in the south of Eastern Siberia, species appeared that had not previously been found here: the Asian Dowitcher Limnodromus semipalmatus, the Pied Avocet Recurvirostra avosetta, the Black-winged Stilt Himantopus himantopus, Spotbill Duck Anas poecilorhyncha. The abundance of many other species of this group of birds has also significantly increased: the Common Crane Grus grus, the Shelduck Tadorna ferruginea, the Gadwall Anas strepera, the Shoveler A. clypeata, the Garganey A. querquedula, the Pochard Aythya ferina, and the Eurasian Curlew Numenius arquata.

The most common phenomenon was the eviction of birds using damp, wet and swampy meadows and shallow waters. In the first wave of mass migrations of birds, the Lapwing Vanellus vanellus, the White-winged Black Tern Chlidonias leucopterus, the Coot Fulica atra, and the Asian Dowitcher were dominant. There were no pronounced mass migrations at this time, although in some areas of the migratory flows of these birds at places of rest stops, there was a noticeable increase in their abundance (Toreyskie lakes, Wetlands complex of the Chivyrykuisky Bay of Lake Baikal, the Barguzin river valley, the Dzhida, Orongoiskaya depression, Goose lake, of the Selenga river delta) [8, 11-12, 14, 17, 23]. The first stage of the eviction of birds is associated with a sharp drying out of the territory and the disappearance of swampy meadows and shallow waters. At this time, the number of coastal birds in the south of Russia begins to increase and new and rare species are found, many of which will later be included in the Red Book of Russia.

3.4. The second stage of the eviction of birds from Central Asia
The next stage (60-70s of the last century) is associated with a decrease in the number of migrating birds and a rather long period of habitat formation under a new regime of moisture supply in Central Asia. However, the establishment in the upper part of the basin Selenga river and adjacent regions of a long dry period (1976-2011) [28] caused the second wave of evictions (80s of the 20th century), including the most widespread and common species of shorebirds and waterfowl. At this time, a significant movement of them to the north was noted, up to the Central Yakut lowland, and in some species even to the tundra zone. The optimisation of the ranges moved from the southern regions of Eastern Siberia and the steppes of Central Asia to Central Yakutia (Central Yakut lowland) [7-9, 11-14, 17, 21, 23]. This was especially noticeable in the common species of waders: the Common Snipe Gallinago, the Pin-tailed Snipe G. stenura, the Swinhoe’s Snipe G. megalus, the Marsh Sandpiper Tringa stagnatilis, the Green Sandpiper T. ochropus, the Wood Sandpiper T. glareola, etc.

During this period, the main number of new steppe species of waders was noted, which had not previously been found in this territory [11-14, 23]. However, all of them were found in the south of Eastern Siberia in flight, with isolated cases of episodic nesting. Among them, the Greater Sand Plover Charadrius leschenaultii, the Lesser Sand Plover Charadrius mongolus, the Oriental Plover Charadrius veredus, the Kentish Plover Charadrius alexandrinus, the Oriental Pratincole Glareola maldivarum and the Gray-headed Lapwing Microsarcops cinereus should be noted. By the end of the 20th century, this process was largely over and the number of coastal birds in the south of Eastern Siberia decreased. On the territory of Mongolia, the abundance of birds remained high only in large lake basins, with a predominance of deep-water lakes. China maintained the water level of reserves created to protect wetland ecosystems only through a special supply of water from large water reservoirs, created artificially - reservoirs on large waterways [11-14, 16, 23]. However, all these measures could not contain the general decline in the number of birds in coastal ecosystems - their abundance here sharply decreased.

At the same time, the number of coastal birds from the southern taiga subzone to the tundra zone has noticeably increased. Their very high abundance was noted in the Lena river delta. However, during the spring and autumn migrations in the southern regions of Eastern Siberia, the number of near-water and waterfowl remained high. Their noticeable concentration was observed on the Angara.
reservoirs, since the main part of the shallow lakes of the forest-steppe and southern taiga had dried up by this time. It was during this period, the end of the 20th - the beginning of the 21st centuries, that the appearance of the Great Cormorant *Phalacrocorax carbo* was recorded in the basin of the lake Baikal and adjacent territories, primarily the Bratsk reservoir. Its mass settlement is associated with a period of significant drying up of Central Asia and the establishment of a long dry period in the basin of the Selenga river [28]. The number of typical ichthyophages has also increased - the Caspian Tern *Hydroprogne caspia*, the Gull-billed Tern *Gelochelidon nilotica*, the Little Tern *Sternula albifrons* and, in part, the Common Tern *S. hirundo*. The sharp decrease in the area of shallow waters in the large lake systems of Inner Asia reduced their fish productivity, associated with the loss of a significant area of spawning grounds.

3.5. *The third stage of the eviction of birds from Central Asia*

In the last years of the 20th and at the beginning of the 21st centuries, the frequency of appearance of typical steppe and mountain birds not associated with wetland ecosystems has increased near the northern boundaries of the ranges. At the same time, an increase in their diversity was observed [11-14, 23]. Among them, there were both small and common species that were not recorded in Eastern Siberia, or earlier their single flights were very rare: Black Vulture *Aegypius monachus*, Greater Short-toed *Calandrella brachydactyla* and Mongolian *Melanocorypha mongolica* Larks, Isabelline *Lanius isabellinus* and Turkistan *L. phoenicuroides* Shrikes, Rose-coloured Starling *S. roseus*, Desert Wheatear *Oenanthe deserti*, Roller *Coracias garrulus*, Bee-eater *Merops apiaster*, Chough *Pyrrhocorax pyrrhocolulus* Alpine Chough *Pyrrhocorax graculus*.

This indicates significant changes in the steppe ecosystems of Central Asia, which is also emphasized by the northward movement of a number of steppe plant species. This period is also characterized by the migrations of new species of coastal birds, against the background of a noticeably reduced number in the southern regions of the Baikal region. Among them, shorebirds from the more southern regions of Asia, previously extremely rare in the south of Eastern Siberia, were noted.

3.6. *The fourth stage of the eviction of birds from Central Asia*

This process gradually intensified, and in the last decade, flights, and, possibly, cases of single nesting sites, have become more frequent in a number of southern species of semiaquatic birds, previously extremely rare in the south of Eastern Siberia. Despite the sharply increased diversity of the bird fauna, their total abundance was insignificant. These are small species with small areas, adapted to the use of very specific environmental conditions. Among them, semi-aquatic, mountain, steppe and desert bird species prevail. In the last two centuries, most of them have not been found in Eastern Siberia, which indicates their southern distribution.

Among them, first of all, it is necessary to note the Little white *Egretta gargarita*, the Purple *Ardea purpurea* and the Cattle *Bubulcus ibis* Herons, the Night Heron *Nycticorax nycticorax*, the Japanese crane *Grus japonensis*, the Swinhoe’s crane *Coscorbina exquisita*, the Red-crested *Netta rufina* and White-eyed *Athyra nyroca* Pochards, Black-tailed Gull *Larus crassirostris*, Turtle *Streptopelia turtur* and Red Turtle *S. tranebarica* Doves, Indian Cuckoo *Cuculus micropterus*, Chinese Yellow Wagtail *Motacilla (tschutschensis) macrorynchus*, Desert Wheatear *Oenanthe deserti*, David’s Laughing Thrush *Garrulus davidi*, Blackbird *Turdus merula*, Plumeous (water) Redstart *Rhyacornis fuligynous* and some other species [12-14, 17, 23].

4. Discussion

A detailed list of birds allows us to highlight the most important aspects of their dispersal and understand the features of the development of this process. It undoubtedly gradually intensified, and in the second decade of this century, birds with more southern ranges began to form the basis of new species, and earlier, even in Mongolia and North China, were few in number for nesting or were found only in flight. It should be noted that the bulk of the new species belonged to migratory birds, or they were occasionally observed on the nesting site in separate pairs or small groups. In this regard, despite
the sharply increased diversity of the bird fauna of Eastern Siberia, the total abundance of new species was insignificant. It was mastered by birds in all directions, but in each large region (Cisbaikalia, the basin of Lake Baikal, Transbaikalia), two or three leading streams were distinguished. The main directions of movement varied by periods of evictions and individual seasons, depending on the localization of areas covered by long dry periods.

It is necessary to pay attention to the fact that droughts and long dry periods covered the desert and steppe natural zones of Inner Asia. Consequently, the birds of these zones should be the most numerous among the settling species. At the same time, it is well known that the diversity of birds in these zones, due to the monotony of the relief and the high severity of living conditions, is low [5, 12-14, 23]. However, the overall bird diversity of this vast geographic region, due to its southern position and high complexity of the relief, is higher than in temperate latitudes. This ensures a high species diversity of migrating birds. The primordial steppe and desert birds, despite the fact that a number of their species are nomadic, have demonstrated very high resistance to dry periods. Undoubtedly, this is due to the formation of special adaptations for their existence in these natural zones. High dynamics of habitats and species diversity is characteristic of birds using intrazonal habitats of these natural zones, which, first of all, include wetland ecosystems.

The complete bird fauna of Eastern Siberia for the end of the 19th - first half of the 20th century, taking into account the new systematic status of a number of species (some subspecies have been converted to species), includes 376 bird species. Their modern fauna (the second half of the 20th and the beginning of the 21st centuries) is formed by 486 bird species, i.e. it has increased by 110 species (22.6%) over the past 70 years. The process of the formation of the bird fauna of Eastern Siberia continues and each year of research brings new species.

5. Conclusion
Thus, mass migrations of birds to the northern boundaries of their ranges as a result of a pronounced warming of the climate are characteristic only of coastal birds that colonize intrazonal habitats that are found in all natural zones and mountain belts - Wetlands ecosystems. Departures of birds from desert and steppe zones (arid territories) covered by severe droughts, with the exception of birds from wetland ecosystems, are limited to isolated cases of flights to the northern boundaries of their ranges, but the frequency of such flights is gradually increasing. The new species are based on migratory southern birds, with isolated cases of episodic nesting of individual pairs and small groups. In this regard, despite the sharply increased species diversity of birds in Eastern Siberia, their total abundance changed insignificantly. Everywhere there is a high instability of habitats and a shift of their boundaries to the north, as well as a noticeable exchange between the bird faunas of different regions, going in all directions, incl. and from the north. Zoogeographic boundaries have also largely lost their significance - birds easily overcome them.

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