Birds of forest ecosystems of Southern Baikal in the conditions of modern climate warming: dynamics of population density and structure in summer

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Abstract. On the basis of long-term works (2010-2022), the materials of studying the influence of climate warming on the bird population of forest ecosystems in the summer period are presented. The main indicators of the bird population were studied: population density and species composition. The dynamics of these indicators of the bird population structure and the features of their structure depending on the level of climate change on the ascending branch of the heat-dry phase of the centuries-old climate cycle, close to completion, are considered. The intensity of bird eviction is associated with the localization of very severe, prolonged and extensive droughts. It is the intensity of evictions that determines the new species composition of birds of the studied territories. They are characterized by very low numbers and therefore there is no clear link between the population density of birds and their species richness. At the same time, the general tendency to preserve this pattern (with an increase in the number of species, the population density of birds increases) is noted in some of their main categories. The obtained materials allow us to find out the peculiarities of the dynamics of the biodiversity of birds in Eastern Siberia during periods of severe climatic anomalies. Such materials are extremely important, as they allow us to find out the real role of natural and climatic factors in the evolution of natural ecosystems and the maintenance of the overall biodiversity of large zoogeographic regions of the Earth.

1 Introduction

The current warming of the climate of temperate latitudes is very well expressed in the territory of Inner Asia and covers the entire Eastern Siberia. The main features of the climate of this territory in summer are associated with the dynamics of the north-west (Atlantic) and south-east (Pacific monsoon) air flows, which determine the weather, climatic and environmental conditions of the region. The northern and southern air flows are of subordinate importance, although sometimes they can also have a strong influence on the climate of Inner Asia. By the middle of the XX century, a noticeable weakening of the

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main north-western air flow was revealed, which was due to a change in the leading directions of movement of air masses. A well-defined latitudinal transfer, due to a sharp increase in solar activity, was replaced by a meridional transfer. After the development of the Pacific meridional flow along the land-sea border, which occurred somewhat later than the western one, the central regions of Inner Asia were covered by severe and sometimes catastrophic droughts – the 40-60s of the last century [1-3]. Then came the period of formation of long periods of low water – up to several decades [4-5]. In this regard, the warming of the climate in Eastern Siberia and, above all, on the lake Baikal and Transbaikalia were significantly stronger than in the adjacent territories [6-7]. Compared with the entire Northern Hemisphere of the Earth, where warming averages 0.7 °/100 years [1-2], in Eastern Siberia and Lake Baikal it reaches 1.9 °C/100 years, i.e. 2.7 times higher [7, 8].

Birds are one of the most mobile elements of natural ecosystems, and can react very quickly to their changes. The general features of their reaction to the ongoing climate changes in Eastern Siberia have already been shown by us in several publications [8-9]. However, identifying changes in the structure of the bird population is a very complex and time-consuming work that requires very long and continuous research. In this paper, an analysis of 13 years of research (2010-2022) on a key site located on the right bank of the source of the Angara River (Southern Baikal) is carried out. It allows us to consider the main issues of the dynamics of the diversity of birds in forest ecosystems in the summer. The greatest attention is paid to elucidating the features of the influence of climate change on the density and structure of the bird population of the forest ecosystems of the studied region. The obtained materials allow us to clarify the role of natural and climatic factors in the evolution of natural ecosystems and the maintenance of the overall biodiversity of Eastern Siberia.

2 Materials and Methods

The physical and geographical characteristics of the area of work in this publication are not considered in detail by us, since it is set out in several of our previous publications [8, 10]. The study of the main indicators of the bird population (population density and species composition) of forest ecosystems in the summer period was carried out on Southern Baikal in 2010-2022. The right bank of the Angara River in its upper course covers the vast Pre-Baikal depression. However, in the area of the source of the Angara River, there is a noticeable increase in terrain – up to 1000 m (the dominant height is 1180 m). Here is the border between the depression itself and the Primorsky Ridge. The first line of ridges adjacent to the lake Baikal and the upper section of the Angara River are characterized by a small height and high steepness of the slopes. Therefore, the decays here have a short length (up to 4-6 km), but a high steepness of the slopes and sharp narrow ridges of the ridges. As you move away from the coast of lake Baikal the relief of this territory is being smoothed out, but still, even in the main decays that dissect mountain ranges into separate segments, the steepness of their slopes remains quite high. The upper part of the key section, directly adjacent to the centerline of the Primorsky Ridge. Its borders are two of large valley rivers – Nikolskaya Bannaja and Krestovka. The maximum height of the watershed between these rivers reaches 810 m, and the heights of the Primorsky Ridge, together with the formation of the sources of these rivers, are 973 m and 1002 m. The total area of the key site exceeds 50 km2 (excluding the steepness of the slopes).

The basis of forest ecosystems in this territory is formed by forests of Common Pine (forest) Pinus silvestris, but pine-birch forests clearly predominate. The general composition of such forests is very complex and includes all tree species found in the
Angara region. At the key site (using cluster analysis), we have identified eight types of bird habitats: they include settlements (villages, urban-type settlements, holiday cottages, sanatoriums, rest homes and sports bases), pine-birch forests with the growth of *Siberian pine* (cedar), spruce floodplain, mixed dark coniferous, aspen-birch, pine, pine-birch forests and open floodplains of rivers. The network of accounting routes evenly covered the entire key area. To account for birds in multi-species communities, a standard methodology was used, which is widely used by ornithologists in Russia. The width of the accounting band was determined based on the average harmonic of the distances of their detection in each type of habitat [11].

We have made some additions to the methodology of accounting work. First of all, we have increased the length of the registration routes, since new bird species appearing here as a result of evictions from the main areas have very low numbers at the initial stages of settlement. Therefore, the intensity of the survey of the territory for their timely detection should be doubled, and for very rare species three times. This made it possible to dramatically increase the volume of collected material and the probability of detecting rare and small species, some of which were new to the Baikal region, the lake basin Baikal and the whole of Eastern Siberia. Characteristics of the bird population structure included four categories of birds. Dominant species - the proportion of birds in a particular habitat or across the entire key site ranged from 10.1% and above. Subdominant species had a share in the population structure from 5.1% to 10.0%. Birds with a share in the total structure from 1.1% to 5.0% are classified as background species. All other species with a share of 1.0% or less in the total population are included in the category of secondary bird species. The total length of the routes for the entire period of research in the summer was 3286.0 km.

Statistical analysis of the collected materials was carried out using the most commonly used and most appropriate research methods. Preference has always been given to nonparametric methods, since they do not require the normal distribution of the collected information required for parametric approaches [12]. In particular, Spearman's rank correlation coefficient was used, which reveals well the connections between features in nonlinear monotonic regression [12]. This is especially important due to the fact that the distributions of the summer bird population according to the main characteristics studied are characterized by polynomial regression of the fifth and sixth degree. The assessment of the level of connection between the features was carried out on the basis of a multiple coefficient of determination (R²) using the Microsoft Exel 2010 charting program for Windows. The species composition and the order of species description are given according to the latest bird reports of the Russian Federation and Siberia [13-14].

### 3 Results

Our research covers the period of maximum climate warming in Eastern Siberia (2010-2022). Currently, there is a tendency to increase the level of humidification of the territory and decrease the rate of climate warming. However, it is virtually impossible to accurately predict the further trend of its dynamics, since cyclical changes are characteristic of the climate. Therefore, the exact allocation of the cycle is possible only in retrospective analysis and for this it is necessary to have a very long series of observations. Currently, most likely, the 2000-year cycle ends with a warm-dry period [8]. Birds are acutely responsive to climate change and are very sensitive indicators of the main trends of its changes. However, there are still very few materials suitable for such analyses.

During the studies, the population density of birds in the key area changed cyclically in the range from 178.2 ind./km² to 334.1 ind./km², i.e. by 1.9 times or 53.3%. In general,
this is a relatively small variability, but it is associated with the registration of new bird species that have never been recorded in this area before. The coefficient of determination, which determines the level of correlation between population density and climate warming trends, selects 32.0% of the total variability of traits (Fig. 1). Such a relationship cannot be called high, but it must be borne in mind that this is clearly cyclical variability, and linear regression is very low and unreliable. Higher indicators of bird population density occur during periods of increasing local surface air temperature, and its low indicators are associated with increased moisture content of the territory of the key site [15].

Fig. 1. Changes in the bird population density of the forest ecosystems of Southern Baikal in the summer period (2010-2022). Source: Compiled by the author.

In recent years, there has been a decrease in surface air temperature due to rainy seasons compared to the previous period. Consequently, the general trend towards a slight increase in bird population density, after its minimum in 2000-2001, may be determined by changes in habitat conditions outside the key area. In part, this is indicated by a sharp increase in the number of the most common species, the Olive-backed Pipit *Anthus hodgsoni*, during the years of high overall bird population density, since its abundance declined sharply in subsequent years. In the same years, the abundance of the Willow Tit *Parus montanus*, another common species of forest ecosystems in the summer, was quite stable or somewhat decreased. At the same time, this decrease was compensated by a fairly high number of the White Wagtail *Motacilla alba* and the Great Tit *Parus major*. In this case, it should be noted that the migratory species was distinguished by a high abundance, and the number of local species of Willow Tit and Great Tit was much more stable. Consequently, the increase in the total population density was due to the redistribution of the Olive-backed Pipit across the territory, the conditions for which at the work site during these seasons improved dramatically. However, this aspect of bird population dynamics requires a separate special analysis (Table 1).

Table 1. The level of correlation between bird population density and the general trend towards climate warming in different categories of birds of the forest ecosystems of Southern Baikal in the summer period (2010-2022)

<table>
<thead>
<tr>
<th>Category of species</th>
<th>Number of species</th>
<th>Density, ind./km²</th>
<th>Correlation coefficient, rs</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant 1-3</td>
<td>63.0-140.2</td>
<td>-0.04</td>
<td>P &gt; 0.05</td>
<td></td>
</tr>
<tr>
<td>Subdominant 1-5</td>
<td>15.1-98.6</td>
<td>0.42</td>
<td>P &gt; 0.05</td>
<td></td>
</tr>
<tr>
<td>Background 10-15</td>
<td>39.0-106.8</td>
<td>0.02</td>
<td>P &gt; 0.05</td>
<td></td>
</tr>
<tr>
<td>Secondary 40-62</td>
<td>23.5-42.0</td>
<td>0.15</td>
<td>P &gt; 0.05</td>
<td></td>
</tr>
<tr>
<td>Total 58-78</td>
<td>178.2-334.1</td>
<td>0.1</td>
<td>P &gt; 0.05</td>
<td></td>
</tr>
</tbody>
</table>
The relationship of bird population density with the general trend towards climate warming is insignificant. It undoubtedly exists, but it does not reach the critical level of reliability of the results obtained (Table 1). Obviously, a longer series of observations is needed to fully and reliably identify this trend. The greatest correlation of population density with the general trend towards climate warming was found in subdominant bird species. Spearman’s rank correlation coefficient (rs) slightly does not reach a critical level of reliability, emphasizing the high importance of this category of birds in the formation of their overall population structure. At the same time, the number of species included in this category is small and usually includes 2-3 species and, as an exception, only one species in some seasons.

We have previously shown that a very high variability of population density over the years is observed in the categories of birds that have a small and unreliable correlation with the general trend towards climate warming [15]. At the same time, all categories of birds are characterized by single, but very sharp outliers of population density in individual seasons, which can determine the general trend of its changes (Figure 2). They are noted in different years and occur only in the first half or middle of the studied period. Outliers often have the form of popping-up options, since they exceed the usual level of bird population density in these categories by more than two times (Fig. 2B, 2C and 2D). Such deviations are determined both by an increase in the total number of registered species and by the relatively high density of their population. The sharp increase in the abundance of subdominant birds in 2017 and 2018 (Figure 2B) is due to an increase in the number of species included in this category (4-5 species) and a relatively high density of their population. Previously, in adjacent seasons, these species were often included in the categories of dominant and subdominant birds. A significant increase in the abundance of background (Figure 2C) birds in 2013 and secondary bird species in 2014 (Figure 2D) is also due to the large number of species included in these categories (15 and 56, respectively), and differing in a higher than usual density of their population.

The most obvious reason for fluctuations in the population density of birds on Southern Baikal in summer is changes in the total number of species registered here. The multiple

![Graph A](image1)
![Graph B](image2)
![Graph C](image3)
![Graph D](image4)

**Fig. 2.** Changes in the population density of birds of the forest ecosystems of Southern Baikal in the summer in different structural categories as the climate warms (2010-2022). Species category: A – dominant, B – subdominant, C – background, D – secondary. **Source: Compiled by the author.**
The determination coefficient selects 54.0% of the total variability of these features, and it is reliable, which indicates a significant relationship between these factors. At the same time, the maximum population density of birds does not always occur in years with a large number of registered species. At the very beginning of the research cycle, the maximum number of registered species was observed, but their population density at that time was the lowest for the entire observation period (Fig. 3).

Correlation analysis shows that the relationship between population density and the number of species in different categories of birds may differ both in level and direction (Table 2). The least and unreliable relationship of these factors is in dominant and background bird species. At the same time, it is very high and reliable in the category of subdominant species, and in secondary bird species it is close to the required critical value (0.41 < 0.55). That is why the overall relationship of these main population parameters in bird populations in summer is quite high. It is far from reaching the critical level required for reliable communication, but there is definitely a trend towards this (Table 2). The overall relationship is negative, i.e. with an increase in the number of species, the population density of birds decreases. The reasons for this are not quite obvious, which requires a more in-depth and special analysis of the collected materials. At the same time, it should be borne in mind that new bird species are extremely low in number, therefore, during periods of their mass evictions, the total number of species increases markedly, but the overall population density of birds very often decreases.

![Fig. 3. The relationship between population density and the number of bird species in the forest ecosystems of Southern Baikal in the summer period 2010-2022. Source: Compiled by the author.](image)

<table>
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<td>0.12</td>
<td>P &gt; 0.05</td>
</tr>
<tr>
<td>Subdominant</td>
<td>1-5</td>
<td>15.1-98.6</td>
<td>0.68</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td>Background</td>
<td>10-15</td>
<td>39.0-106.8</td>
<td>0.19</td>
<td>P &gt; 0.05</td>
</tr>
<tr>
<td>Secondary</td>
<td>40-62</td>
<td>23.5-42.0</td>
<td>0.41</td>
<td>P &gt; 0.05</td>
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<td>-0.15</td>
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</tr>
</tbody>
</table>

Table 2. The level of correlation between population density and the number of species in different categories of birds of the forest ecosystems of Southern Baikal in the summer period (2010-2022).

An additional analysis of the level of correlation between these population indicators shows that dominant, background and secondary bird species have a significant spread of these indicators over different seasons (Figure 4A, 4C and 4D). Obviously, it is this fact
that determines the low and unreliable level of the relationship between the population density of birds and the number of species recorded in a particular observation season in these categories. At the same time, the relationship between population density and the number of bird species is clearly visible, although in most observation seasons both of these parameters are very close to the average level. The spread of the same indicators in the category of subdominant bird species is small, which determines the high level of connection between the population parameters under consideration. It is also necessary to pay attention to the obvious population density outliers in these categories (Figure 4A, 4C and 4D), which we noted earlier when analyzing the general trend of changes in bird population density as the climate warms.

At the same time, the coefficients of multiple determination in all cases have medium (41.2% background and 47.3% secondary species) or high levels (77.3% dominant and 84.9% subdominant species). This highlights a fairly high correlation between the level of population density and the total number of registered species, even in different categories of birds. The overall relationship of these indicators is at an average level – 54.0% (Figure 3).

![Figure 4](image)

**Figure 4.** The relationship of population density and the number of bird species in the forest ecosystems of Southern Baikal in summer in different structural categories as the climate warms (2010-2021). The category of species: A – dominant, B – subdominant, C – background, D – secondary. *Source: Compiled by the author.*

It is this circumstance that largely determines the level of correlation between these population parameters in the bird categories under consideration (Table 2). At the same time, it is, in most cases, low and is most likely determined by a large number of new bird species registered at the key site. We need a more detailed analysis of the relationship of these population indicators for each species noted at this time. However, it is extremely cumbersome. Therefore, it is necessary to consider it in a separate special publication.

**4 Discussion**

In previous studies, we have shown a significant increase in the number of new bird species due to modern climate warming [8-9, 15]. Compared with the end of the XIX – the first half of the XX century, the number of birds in the summer period at the key site has increased by 31 species. Of these, 26 species are characteristic of the entire Prebaikal region or only for the southwestern coast of lake Baikal. In addition, there is a clear shift to the north of the distribution and nesting boundaries of the most common and mass species of sedentary
birds: Long-tailed Tit *Aegithalos caudatus*, Coal Tit *Parus ater*, Great Tit *Parus major*, Great Spotted Woodpecker *Dendrocopos major*, etc. [15].

In total, out of 31 bird species found in the forest ecosystems of the Baikal region as new and stray for the second half of the XX – beginning of the XXI centuries, only 5 species are common with the past period. They were recorded here in the late XIX – first half of the XX centuries (Chaffinch *Fringilla coelebs*, Oriental Reed Warbler *Acrocephalus orientalis*, Chestnut Bunting *Ocyris rutilus*, Whitethroat *Sylvia communis* and Golden Oriole *Oriolus oriolus*) [15]. Only two of these species, the Chaffinch and the Chestnut Bunting, have spread widely across the territory and dramatically increased their numbers. The Chaffinch went far to the southeast and reached the Primorsky Territory, although its number in the east of its range, starting from Transbaikalia, is very low. The Chestnut Bunting has greatly advanced its range to the northwest, up to the mouth of the Angara River. However, its number varies greatly by head and its sharp increase is observed in colder seasons, characterized by increased humidification of the region. The other three species are small breeding species of the territory under consideration. However, it should be borne in mind that previously they were either very rare or related exclusively to stray birds.

All other 26 species are new to the Prebaikal region. For some of them, nesting in a key area has been noted in recent years (Japanese Quail *Coturnix japonica*, Wood Pigeon *Columba palumbus*, Stock Dove *Columba oenas*, Chinese Yellow Wagtail *Motacilla (ttschutschensis) macronix*, Azure-winged Magpie *Cyanopica cyanus*, Grasshopper Warbler *Locustella naevia*, Greenfinch *Chloris chloris*, Linnet *Acanthis cannabina*). At the same time, in neighboring territories, some of these species are more common nesting, flying or flying birds, in some cases reaching a sufficiently high number (Japanese Quail, Grasshopper Warbler). Given the small area of the key site, it is necessary to recognize that changes in the habitats of birds of forest ecosystems during the summer period undoubtedly exist and are well expressed. This is also confirmed by a detailed analysis of the dynamics of bird ranges in Eastern Siberia. Currently, 114 new bird species have been registered in this region, which have never been recorded on its territory before [9].

The relationship of the dynamics of the species richness of birds with the general tendency to climate warming in summer is quite significant and is well approximated by a polynomial regression of the 6th degree. The coefficient of determination of this relationship selects about 70.0% of the total variability of these features, but the rectilinear relationship is very weak and unreliable. This relationship easily explains the dynamics of the species composition of birds - species richness is associated with the density of the bird population. It usually increases as the number of registered species increases. However, in our case, such a connection is not quite obvious. During the period of a sharp decline in bird population density (2015-2017) (Figure 1), species richness remained at a fairly high level, even for a short period of time between the next cycles. At the same time, the general downward trend is being captured quite well.

Most likely, the dynamics of this indicator in the summer period at the key site reflects the general trend of changes in the species structure of birds throughout Eastern Siberia. Currently, the general trend towards climate warming is ending. However, it is possible that this will be observed in a short time period within the framework of the 11-year climate cycle. Currently, birds are moving from the southern parts of their ranges in waves of north-western, north-eastern and south-eastern directions associated with the areas of formation of severe extensive droughts and long periods of low water. The northern direction of movement is general and characteristic of all species that have changed the boundaries of their ranges. The general decrease in the number of new bird species in Eastern Siberia is due to the general trend towards the restoration of the previous climatic conditions, which is confirmed by the beginning of filling of the previously dried-up large
lakes of Transbaikalia, Mongolia and Northeastern China. This trend is also well noted when working on a key site on the right bank of the source of the Angara River.

5 Conclusion

The supposed clear relationship between bird population density and species richness (number of species) turned out to be much more complicated. The obtained levels of such a relationship show that it is poorly visible on the general graphs of these factors and is not always clearly captured when analyzing birds of different categories separately. A higher correlation is noted in the categories of small bird species. And, as it has now become clear, this is determined by the fact that the main part of the evicted birds of forest ecosystems occurs, especially at the initial stages of this process, in individuals, pairs and small groups of 3-5 birds. In order to track such a situation, it is necessary to cover a very vast territory. The main reason for this is due to the fact that the appearance of new species in the key area and in Eastern Siberia during the summer periods of strong warming, in general, is determined by the processes of their evictions from Central Asia. They are associated with the localization of large-area droughts and long-term low-water periods. Birds of forest ecosystems withstand stronger climate fluctuations compared to waterfowl and near-water birds. For the latter, severe droughts dramatically reduce the area of habitable reservoirs and wetlands – they react to the desiccation of the territory in the first place. Therefore, the main reaction of forest birds to climate warming at the initial stages of this process is associated with their redistribution across the territory. And only very severe droughts are the trigger mechanism leading to the mass eviction of such species to the northern borders of their habitats. It is very difficult to accurately determine the beginning of this process, working on relatively small key areas. It is necessary to analyze the situation in large regions and these tasks can be performed only with the use of an extensive network of specially protected natural areas. Only such an approach will provide sufficient materials for a full assessment of the characteristics of the dynamics of bird biodiversity within large zoogeographic regions during periods of severe climatic anomalies. However, such materials are extremely important, as they allow us to find out the real role of natural and climatic factors in the evolution of natural ecosystems and the maintenance of the overall biodiversity of large zoogeographic regions of the Earth.

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