Modern climate changes and dynamics of density and structure of bird population of South Baikal of forest ecosystems in winter period

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Abstract. On the basis long-term researches (2010-2021), the features of the formation of the winter population of birds on the right bank of the source of the Angara river (South Baikal) during a period of sharp climate warming are considered. It is shown that the warming was accompanied by a gradual decrease in the total density of the bird population and a noticeable increase in their species diversity. On the key site, were 73 wintering species recorded, of which 28 were new to the region. However, 24 species were previously in this area as nesting, migratory and summering birds found. Only 4 species were really new. All new wintering species differed in insignificant numbers and the increase in the number of wintering species was due to an increase in the comfort of the living conditions of birds as result of climate warming. The relationship between population density birds and the number of wintering species was clearly in certain categories manifested, and only in minor species did it play a certain role in increasing their population density. The reformation of the structure of the bird population in the winter period due to the noticeable warming of the climate was almost completely by the dynamics of the population of the most massive and numerous species of sedentary and migrating for wintering species determined. The decrease in the abundance of birds is clearly associated with a shift in the optima of their ranges to more northern regions.

1. Introduction

The current warming of the climate of temperate latitudes is most in the territory of Inner Asia pronounced and covers the whole of Eastern Siberia. The main climatic characteristics of this territory in winter are associated with the dynamics of the Asian anticyclone, which determines the weather, climatic and ecological conditions of the region [1-3]. At the beginning of the XXI century, its significant weakening was revealed, associated with the increased influence of southern warm air masses on it. The current increase in the frequency of positive anomalies in winter temperatures in Eastern Siberia, reaching record values for the entire period of instrumental study of the climate, is clearly associated with the weakening of the Asian anticyclone [1-3]. Probably, this is also associated with a more pronounced warming in Eastern Siberia and, first of all, in Lake Baikal and Transbaikalia in late winter and early spring periods. On the lake Baikal, the winter surface air temperature has increased by almost 8.0° C, and the water surface temperature in the summer by 2.0-2.5° C [4]. Compared to the entire Northern Hemisphere of the Earth, in which the average warming is 0.7° C/100 years [4-5], in Eastern Siberia and Baikal it reaches 1.9° C/100 years, i.e. 2.7 times higher [6-7].
Birds are one of the most dynamic elements of natural ecosystems, reacting very quickly to their changes. The general features of their response to the ongoing climate changes in Eastern Siberia have been in several publications shown [7-12]. However, it is rather difficult to identify changes in the structure of the bird population, first of all, because for this it is necessary to have a sufficiently long series of continuous observations. This paper presents an analysis of 12-year studies at a key site located on the right bank of the source of the Angara river. It allows you to answer a number of questions related to the elucidation of the influence of climate dynamics on the density and structure of the bird population in the forest ecosystems of Southern Baikal (Eastern Siberia).

2. Material and methods

The physical and geographical characteristics of the area of work are in sufficient detail by us in several publications described and in this case is not considered [6, 8-9, 11]. The study of the dynamics of population density and species structure of birds in the forest ecosystems of Eastern Siberia in winter was on South Baikal in 2010-2020 carried out. In the area of the source of the Angara river, there is a noticeable increase in the terrain - up to 1000 m (dominant height 1180 m). The boundary between the Pedbaikalsky foredeep and the Primorsky ridge passes here. Small and short ravines (up to 4-6 km) facing the Larch Bay of Lake Baikal and the source of the Angara river have a steep slope and sharp narrow ridges. As you move away from the coast of the lake the mountainous relief of Lake Baikal is noticeably smoothed out, but nevertheless, even in large ravines, the steepness of their slopes remains high. The key site is directly adjacent to the centerline of the Primorsky Ridge. Its borders are two large ravines - Nikolskaya Bannaya and Krestovka. The maximum height of the watershed between these rivers reaches 810 m, and the height of the Primorsky Ridge in place formation of the sources of these rivers is 973 m and 1002 m. The total area of the key site is more than 50 km² (excluding the steepness of the slopes).

Common pine (forest) Pinus silvestris forests are usually in this area, but pine-birch forests clearly predominate. However, the composition of such forests is very complex and includes all tree species found in the Angara region. At the key site, using cluster analysis, eight types identified of bird habitats were. They include settlements, pine-birch forests with Siberian pine undergrowth (cedar), spruce floodplains, mixed dark conifers, aspen-birch, pine, pine-birch forests and open river floodplains [11-12]. In the course of registration work was, a network of routes laid, covering the entire cultivated area. A standard technique was that is widely used by Russian ornithologists for counting multi-species bird communities used, and the width of the counting strip was determined on basis of the harmonic mean of the distances of their detection [13]. We have made some additions to the methodology for conducting accounting work. The changes relate to the frequency of accounting work, the allocation of extrapolation arenas, the determination of the required amount of accounting material, the laying and length of accounting routes. To characterize the structure of the population, the dominant were species with the proportion of birds in a specific habitat or throughout the key site from 10.1% and more. Subdominant species have a share in the population structure from 5.1% to 10.0%. The background species includes birds with a share in the total structure from 1.1% to 5.0%. All other species with a share of 1.0% or less in the total population are included in the category of minor bird species.

The total length of routes for the entire period of work in winter was 3014.3 km. Statistical analysis of the collected materials was carried out using the most frequently used methods that best suit the research objectives [14]. The species composition and the procedure for describing species are according to the latest bird reports of the Russian Federation and Siberia given [15-16].

3. Results

For the period of work (2010-2021), which is characterized by the warmest climate for the entire period of instrumental studies, the total bird population density at the key site varied from 64.5 ind./km² to 152.9 ind./km² from year to year. The amplitude of its changes reached 2.4 times or 57.8 %. Despite the noticeable variations in this indicator, there is a clear tendency to its decrease by the end of the observation period (figure 1). The coefficient of determination, which determines the level of relationship between the density of the bird population and the general trend towards climate warming, selects 51.0 % of the
The total variability of these characteristics. Therefore, this relationship is essential and must be into account taken. The population density of wintering birds is clearly determined by changes in the abundance of the most numerous sedentary and migratory species. Noticeable increases in population density are in years of high abundance of wintering northern species observed. For this area of the lake Baikal is characterized by massive raids of the Waxwing Bombycilla garrulus, Redpoll Acanthis flammea, Pine Grosbeak Pinicola enucleator, the Long-tailed Tit Aegithalos caudatus, and sometimes the Great Tit Parus major and the Great Spotted Woodpecker Dendrocopos major. A certain role in this process is by the breeding success of the Great Tit played in years with early and warm spring, feeding 2-3 broods during the summer. At times, a not very pronounced, but quite obvious (very harsh winters) is noticeable, the approach for wintering of the Willow Tit Parus montanus, Marsh Tit Parus palustris and, as an exception, the Siberian Tit Parus cinctus, the Coal Tit Parus ater, the Baikal Bullfinch Pyrrhula cineracea, the Eurasian Bullfinch Pyrrula pyrrhula, Nutcracker Nucifraga caryocatactes and Tree sparrow Passer montanus. The latter species is only in settlements observed. Plaques of Crossbills (Common Crossbill Loxia curvirostra and Two-barred Crossbill Loxia leucoptera) are extremely rare in winter. South Baikal is by oppressed, very swampy spruce forests characterized with very low seed yields. At the same time, late summer and autumn movements of these species are quite common here.

![Figure 1](image)

**Figure 1.** Changes of population density birds in the forest ecosystems of Southern Baikal in winter as the warms climate (2010-2021). *Source: Compiled by the author.*

The downward trend in bird population density (negative correlation) as the climate warms in winter is well in all categories of birds manifested (table 1). Therefore, it is not surprising that this trend is very clearly in the general density of their population manifested. However, a significant correlation of these characters is only in two categories - in dominant and minor species (table 1). The reasons for this trend can be very diverse, and therefore, to clarify them, a more detailed analysis of the collected information is required.

**Table 1.** The level of correlation between the density of bird populations and the general trend towards climate warming in different categories of wintering birds in the forest ecosystems of Southern Baikal (2010-2021).

| No. | Species category | Number of species | Density, ind./km² | Correlation coefficient | Reliability |
|-----|------------------|------------------|-------------------|-------------------------|-------------|
| 1   | Dominant         | 2-5              | 46.4-94.7         | -0.79                   | P < 0.01    |
| 2   | Subdominant      | 0-5              | 4.9-60.2          | -0.16                   | P > 0.05    |
| 3   | Background       | 5-9              | 11.1-26.9         | -0.49                   | P > 0.05    |
| 4   | Secondary        | 21-32            | 4.2-13.7          | -0.6                    | P < 0.05    |
|     | Total            | 33-44            | 64.5-152.9        | -0.71                   | P < 0.01    |

Source: Compiled by the author.
A very high variability of population density indicators over the years is in the noted categories of birds that have a small and insignificant correlation with the general trend towards climate warming (subdominant and background species). At the same time, rare but very sharp outbursts of population density in individual winter seasons are characteristic of subdominant and secondary bird species, which can determine the general trend of its changes (figure 2). They were in noted different years and are only in the first half of the studies found. Emissions appear to be a bouncing option, as they are more than double the normal density of bird populations in these categories (figure 2B and 2D). Such deviations are determined both by the increase in the total number of species recorded in these categories during the given observation period, and by the relatively high density of their population. The sharp increase in the abundance of subdominant birds in 2015 (figure 2B) is due to the increase in the number of species included in this category (5 species) and the relatively high density of their population. Earlier, in adjacent seasons, these species were often included in the category of dominant birds. A significant increase in the abundance of minor species in 2011 (figure 2D) is due to the massive appearance of the invasive species - the common tap dance and the transition, in this regard, of several background bird species to the category of minor species. In this case, these species also had a higher population density.

Figure 2. Changes in bird population density in forest ecosystems of Southern Baikal with climate warming in structural categories of wintering birds (2010-2021). Species category: A - dominant, B - subdominant, C - background, D – secondary. Source: Compiled by the author.

The most obvious reason for fluctuations in the population density of wintering birds in Southern Baikal, not related to the intensity of their approach for wintering, is the number of wintering bird species. The additional analysis carried out confirms the existence in the winter period of a fairly well expressed and reliable relationship between these population parameters (figure 3). The multiple determination coefficient selects 55.0% of the total variability of characters, which indicates a fairly significant relationship between these population parameters. At the same time, one cannot exclude the existence of differences in the level of this connection between different categories of wintering birds.
Correlation analysis shows that the relationship between population density and the number of species in different categories of birds can differ both in level and direction (table 2). It is the smallest, negative and unreliable in dominant and background bird species. At the same time, this relationship is very high and reliable in subdominant and secondary species. That is why the general relationship of these parameters in populations of wintering bird species is quite high and reliable (table 2). The reasons for this are not entirely obvious, which requires a deeper and more specialized analysis of the collected materials.

**Table 2.** The level of correlation between the population density and the number of species in different categories of wintering birds of the forest ecosystems of South Baikal (2010-2021).

| No. | Species category | Number of species | Density, ind./km² | Correlation coefficient | Reliability |
|-----|------------------|-------------------|-------------------|------------------------|-------------|
| 1   | Dominant         | 2-5               | 46.4-94.7         | -0.12                  | P > 0.05    |
| 2   | Subdominant      | 0-5               | 4.9-60.2          | 0.93                   | P < 0.001   |
| 3   | Background       | 5-9               | 11.1-26.9         | -0.02                  | P > 0.05    |
| 4   | Secondary        | 21-32             | 4.2-13.7          | 0.82                   | P < 0.01    |
|     | Total            | 33-44             | 64.5-152.9        | 0.74                   | P < 0.01    |

Source: Compiled by the author.

Additional analysis of the level of association between these population indicators shows that the dominant and background bird species have a significant variation in indicators for different seasons (figure 4A and 4C). Obviously, it is this fact that determines the low and unreliable level of the relationship between the density of the bird population and the number of species recorded in a particular observation season in these categories.

At the same time, in this case, the relationship between the 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 scatter of the same indicators in the categories of subdominant and secondary bird species is small, which determines the high level of correlation between the considered population parameters. It is necessary to pay attention to the obvious outliers of population density in these categories (figure 4B and 4D), which we noted earlier when analyzing the general trend of changes in bird population density with climate warming (figure 2B and 2D). They are undoubtedly due to the increase in the number...
of registered species. It is this circumstance that largely determines the high level of correlation between these population parameters in these categories of birds (table 2).

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

4. Discussion
In previous studies, using Lake Baikal hollow as an example, a significant increase in the number of new wintering bird species was, due to the current climate warming shown [7-12]. Compared to the end of the 19th century - the first half of the 20th century, the number of wintering birds in this region of Eastern Siberia has increased by 41 species [9]. On the territory of the key site, 28 new species were in winter recorded, of which 24 species were for the first time encountered. However, all these species were found on this territory during the periods of migration, nesting, as well as in the categories of flying or even wintering birds in other regions of Eastern Siberia (as a rule, more southerly). Only four wintering species were not previously on the southwestern coast of Lake Baikal or in Cisbaikalia (at the end of the 19th - the first half of the 20th centuries) recorded: Wood Pigeon Columba palumbus, Japanese Waxwing Bombycilla japonica, Gray-backed Thrush Turdus hortulorum, and Greenfinch Chloris chloris. Consequently, the increase in the number of new wintering species was due to an increase in the comfort of the living conditions of birds in the winter as result of climate warming. However, most of these species belong to the category of forced wintering birds. Of the 28 new bird species, 22 species are found only within settlements, and 6 species can be noted in their vicinity.

Simultaneously with an increase in the species diversity of wintering bird species, i.e. the number of new species, there is a gradual decrease in the density of their population. This is a general pattern, since practically throughout the entire European part of Russia in temperate latitudes, as the climate warms in winter, a decrease is in the bird population density observed [17-18]. Most likely, this phenomenon is associated with a shift in the optima of the wintering habitats of birds to more northern areas. This is by a decrease indicated in the abundance of both sedentary and wintering bird species. In conditions of
climate warming, one would expect at least stabilization, and at best, an increase in the population density of sedentary bird species.

Although there is a clear relationship between population density and the number of recorded bird species, it is not very clear. There are many violations of this pattern, and all of them are associated with a high population density of certain species of sedentary or migrating for the winter of common bird species. In all cases of increased population density, a sharp increase is in 1-3 dominant or subdominant bird species observed and a shift of more common species to the next category of abundance. Due to this, the total density of the bird population of forest ecosystems in the winter period significantly increases. An increase in population density due to an increase in the number of species in certain categories of birds is a rather rare phenomenon, although it can be in all categories of birds observed. To obtain a complete picture of the formation of the winter population of birds in modern conditions, a detailed analysis of the dynamics of the population of the most abundant and common species of wintering birds is required.

In general, the increase in the number of new wintering bird species did not lead to an increase in their population density, although it sharply increased their overall diversity. All new species are extremely small in number and remain for wintering only in certain areas with the most optimal winter habitat conditions. Among them, species predominate in the diet of which plant seeds prevail, as well as berries and fruits of shrubs and small trees, which are in mass in settlements found. In addition, the population density of wintering birds of prey may increase, but only in years of abundance of basic food. In this case, waterfowl and waterfowl are no exception - species that feed on fish and small invertebrates gain advantage.

5. Conclusion
A noticeable warming of the climate in the second half of the 20th and the beginning of the 21st century greatly increased the species diversity of wintering birds, but had very little effect on the change in the total density of their population. The overwhelming majority of new species are here as single specimens, in small groups and flocks from 2-3 to 10-15 individuals found. At the same time, in the group of minor species characterized by an extremely low population density, a short-term increase in this population indicator is possible due to a sharp increase in the number of wintering bird species. However, such an increase has little effect on the total population density of wintering birds. In the modern period, there is a well-pronounced tendency towards a decrease in the total population density of wintering bird species as the climate becomes warmer. Most likely, it is by the displacement of the optima of the wintering habitats of birds to more northern regions determined. The reformation of the structure of the bird population in winter is almost determined completely the dynamics of the population density of the most abundant and numerous birds of sedentary and migratory species for wintering.

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