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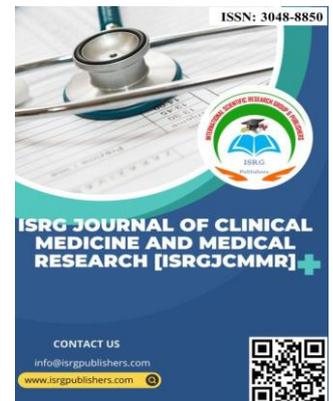
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Climate change impact on Forest birds of Mongolia

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Abstract

It is crucial to base biodiversity and environmental research and analysis at all levels on global adaptation to climate change and on scientifically grounded planning. In particular, the impact of warming on forests- an important resource covering a small percentage of our country's territory- could have significant consequences for biodiversity. The study aimed to clarify how climate change affects habitat modeling, focusing on birds, an essential component of forest ecosystems.

*The research modeled the impact of climate change on six bird species found in forests, from the baseline year 2000 to 2020, 2050, 2080, and 2100. The species included the Common Cuckoo (*Cuculus canorus*), Eurasian Three-toed Woodpecker (*Picoides tridactylus*), Great Spotted Woodpecker (*Dendrocopos major*), White-backed Woodpecker (*Dendrocopos leucotos*), Eurasian Nuthatch (*Sitta europaea*), and Meadow Bunting (*Emberiza cioides*). The habitats of these six species were modeled, with their distribution areas classified into two categories: Core habitat and Range habitat. The Core habitat encompassed the top 90-100% of habitats, while Range habitats included areas with at least 50% of the modeled raster values. Climate change scenarios for future warming- +2°C, +3°C, and +5°C- for the periods 2021-2040, 2041-2060, 2061-2080, and 2081-2100 were derived from the World Climate and Meteorological Database (www.worldclim.org). These scenarios correspond to near- term (around 2030), mid- term (around 2050), long-term (around 2070), and very long-term (around 2090) projections. The temperature increases were coded as +2°C (0.9-2.2°C), +3°C (2.1- 4.3°C), and +5°C (+3.8-7.4°C). These were represented as 126, 245, and 585 by HadGEM3-GC31-LL, based on 30-second spatial resolution data (https://www.worldclim.org/data/cmip6/cmip6_clim30s.html). The study also examined how the distribution of six bird species, three natural berry species, and three insect species might change under these climate scenarios.*

According to a Hotspot analysis of all 40 bird species, habitat overlap with the Core habitat for 0-2 species was estimated at 533,225.1 sq.km; for 3-6 species at 148,455.4 sq.km; for 7-12 species at 22,712.0 sq.km; for 13-25 species at 4,883.9 sq.km; and the overlap with the Range habitat was estimated at 952,841.2 sq.km; for 4-8 bird species at 793,935.1 sq.km; for 9-13 species at 400,414.3 sq.km; for 14-19 species at 167,525.2 sq.km; and for 20-32 species at 40,829.1 sq.km across Mongolia's forested areas.

Keywords: forest birds, fruits, insects, habitat modelling, climate change

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) Working Group 1 (WP1 AR5 2013), there is a high degree of certainty that climate change is occurring and that human activities are the main cause (Dagvadorj et al., 2014). Over the past four decades, warming has occurred across all natural regions, and although they are spatially and geographically distant, the warming has been consistent (Batjargal and Enkhjargal, 2013). According to data from 48 meteorological stations across Mongolia from 1940 to 2013, the average surface temperature (at a height of 2 meters) has warmed by 2.07°C, with warming more intense in mountainous regions and less intense in the Gobi and steppe regions. The warmest 10 years in the last 74 years have all occurred since 1997 (Dagvadorj et al., 2014). Researchers have documented the distribution of 39 ecosystem-important bird species from 6 Orders, 16 Families, and 28 genera in the forested regions of Mongolia, most of which are assessed as “data deficient” at the regional and international levels according to the IUCN Red List criteria, indicating a lack of knowledge and application of the relationship between forests and birds. Given the intensity of climate change and its potential impacts on the environment, biodiversity, and ecosystem integrity in this century, it is necessary to emphasize the role and participation of birds in future research and conservation planning (Baseline Research Report, 2025; Enkhbileg et al., 2025). By focusing on the integrity and balance of forest ecosystems, including the stability of the environment, the normal conditions of ecosystem services in watershed forests, and the impact of climate change, it will be possible to identify and plan the conservation of biodiversity components that play an important role in the conservation of our country's valuable resources and the high socioeconomic importance of forests and their surrounding regions.

Methods

The researchers' previous forest bird data were compiled and updated, enriched with research data from 2022-2024, and, based on them, the habitat was mapped in detail using the MaxEnt 3.4.4 (www.biodiversityinformatics.amnh.org/open_source/maxent) modeling method. Six representative species were selected from 39 bird species distributed in the Khangai and Khentii Mountain forests and forest-steppe regions of Mongolia, and the distribution and habitat changes of three species of harmful insects and three fruit species that overlap with these birds were also considered. The study used a base year of 2000 and short-term (2021-2040), medium-term (2041-2060), long-term (2061-2080), and future (2081-2100) climate models (www.worldclim.org) to model, develop, map, and estimate changes in the habitat and distribution of the species. The modeling included climate variables such as bioclimatic bio-19 (BIO19), solar radiation (SRAD12), wind speed (WIND12), and water vapor pressure (VAPR12) (www.worldclim.org), aridity (ARID7), and snow cover (SNOW7), along with 28 other layers of natural and environmental variables, including elevation-surface (www.worldclim.org), desertification, plants, ecosystems, soils, forests, forage plants,

landscapes, permafrost, natural zones, basins, soils, and vegetation of Mongolia (www.eic.mn), and ecological regions and biomes (www.arcgis.com/home). A total of 115 filters or layers were used for 11 forest fruits or berries and 9 pest insect species. A total of 1950 data points for 39 bird species, 639 for 6 insect species, and 670 for 11 fruit species were used in the modeling study. The model realistically simulated the species' distribution and, using the Jackknife test, revealed how each variable affected the distribution by its share. The model's receiver operating characteristic (ROC) and characteristic performance (AUC) were used as allowed.

Each species' modeling was replicated 3 times (Replicates), and therefore, the average (AVG) was selected and used as the result. The habitats of 6 bird species, their prey (insects), and berries were mapped, and habitat polygons were calculated by classifying the raster layers into two categories: Core Habitat and Range Habitat. The raster (AVG) product from the simulation was converted to the WGS84 projection using ARCGIS 10.6.1, and the habitat layer was classified into Natural Breaks (Jenks) 5. The potential area above the average ($\geq 0.4\%$) or 50% was divided into two main variants: “Range habitat”, and the Core habitat above the highest ($\geq 0.8\%$) value was divided into two main variants, which were converted into polygons. The area was calculated and evaluated in sq.km and compared graphically and statistically.

Result and Discussion

Of the 520 bird species recorded in Mongolia, about 240 species (46.1%) are residents and migratory birds distributed in forests. For the modeling study, 40 bird species were selected as representatives, considering their habitat and feeding characteristics. According to the habitat modeling of the 40 forest bird species and HotSpot, the Core habitat was estimated at 533,225.1 sq.km for 0-2 species, 148,455.4 sq.km for 3-6 species, 22,712.0 sq.km for 7-12 species, and 4,883.9 sq.km for 13-25 species, and the Range habitat overlapping 4-8 species at 952,841.2 sq.km, 793,935.1 sq.km for 4-8 species, 400,414.3 sq.km for 9-13 species, 167,525.2 sq.km for 14-19 species, and 40,829.1 km² for 20-32 species. However, the total area overlapping (Hotspot) of 6 species of pest insects fed upon by forest birds was 81,690.5 sq.km for 0-1 species, 12,604.8 sq.km for 2 species, and 2,962.9 sq.km for 3-5 species of Core habitat, while the Range habitat overlap between 0-1 species was 437,894.1 sq.km, 96,606.2 sq.km for 2 species, and 45,217.2 sq.km for 3-5 species. Also, the habitat overlapping of the 11 common species of natural berries, Core habitat that is commonly distributed and included in food by birds, was determined at 235,322.5 sq.km for 0-2 species, 96,409.8 sq.km for 2-4 species, and 21,638.6 sq.km for 5-8 species, while the Range habitat was 696,077.5 sq.km for 0-2 species, 397,387.7 sq.km for 3-5 species, 164,363.5 sq.km for 6-7 species, and 59,350.5 sq.km for 8-10 species at all.

Changes in bird habitats and distribution due to climate change

The habitats and distributions of six species of forest birds in Mongolia, such as Common Cuckoo (*Cuculus canorus*), Great Spotted Woodpecker (*Dendrocopos major*), White-backed Woodpecker (*Dendrocopos leucotos*), Meadow Bunting (*Emberiza cioides*), Eurasian Three-toed Woodpecker (*Picoides tridactylus*), and Eurasian Nuthatch (*Sitta europaea*), are expected to be changed under future climate change projections. Monitoring changes in the habitats of birds that play an important role in the balance of forest ecosystems is not only an important basis for conservation but also for basic science for socio-economic development policies.

Near-term climate change scenario (2021-2040) in Range Habitat

The range habitat of the six bird species is projected to increase by 13.9%, 9.8% and 13.3% from the average range of 2000

(avg=259,634.5 sq.km) to 338,096.6 sq.km (avg=47,288.6 sq.km), 325,959.7 sq.km (avg=29,151.7 km²) and 336,253.8 sq.km (avg=39,445.8 km²) respectively, under a near-term climate change scenario of +2, +3 and +5°C warming between 2021 and 2040 (around 2030) (Figure 1). For each bird species, the average range of +2, +3 and +5°C changes (n=3) around 2030 is expected to be decreased by -1,09.2 sq.km for the Common Cuckoo (*Cuculus canorus*), increased by 57,934.2 sq.km for the Great Spotted Woodpecker (*Dendrocopos major*), decreased by -6,389.7 sq.km for the White-backed Woodpecker (*Dendrocopos leucotos*), decreased by 51,985.9 sq.km for the Meadow Bunting (*Emberiza cioides*), increased by 83,871.4 sq.km for the Eurasian Three-toed Woodpecker (*Picoides tridactylus*), and increased by 33,469.8 sq.km for the Eurasian Nuthatch (*Sitta europaea*).

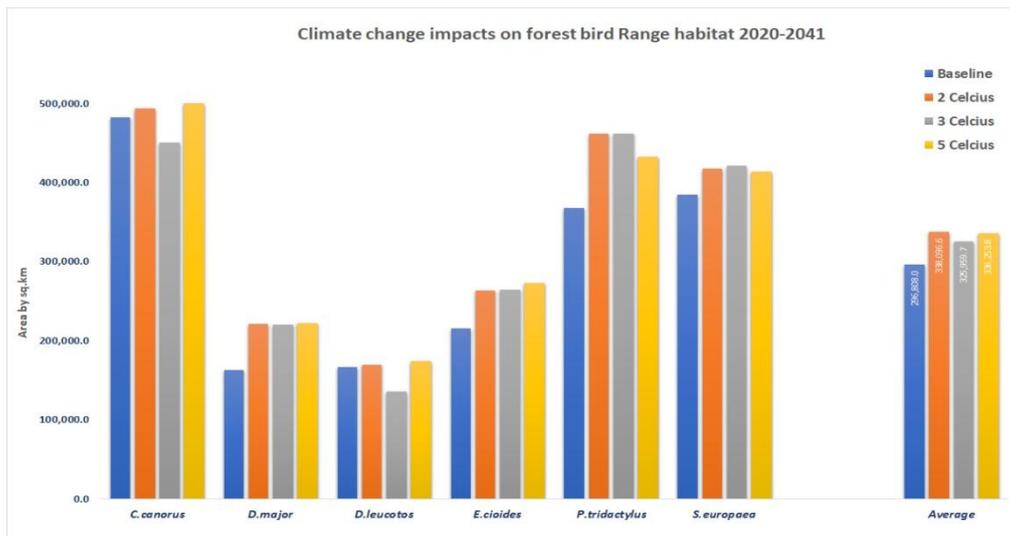


Figure 1. Climate change impacts on forest bird Range habitat 2020-2041

Near-term climate change scenario (2021-2040) in the Core habitat

In the near-term, climate change of the Core habitat average (avg=45,594.3 sq.km) of 6 bird species is projected to warm by +2, +3, and +5 degrees Celsius around 2030, increasing by 23%, 21.2%, and 17.8% from the base year average, respectively, to 56,097.5 sq.km (avg=10,503.2 sq.km), 55,238.7 sq.km

(avg=9,644.4 sq.km), and 53,727.5 sq.km (avg=8,133.1 sq.km) (Figure 2). For each species, the average range of +2, +3 and +5°C changes (n=3) around 2030 is expected to increased by 12,396.9 sq.km for the Common Cuckoo (*Cuculus canorus*), 5,682.9 sq.km for the Great Spotted Woodpecker (*Dendrocopos major*), 205.5 sq.km for the White-backed Woodpecker (*Dendrocopos leucotos*), 13,013.4 sq.km for the Meadow Bunting (*Emberiza cioides*), 19,017.6 sq.km for the Eurasian Three-toed Woodpecker (*Picoides tridactylus*), and 6,245.1 sq.km for the Eurasian Nuthatch (*Sitta europaea*).

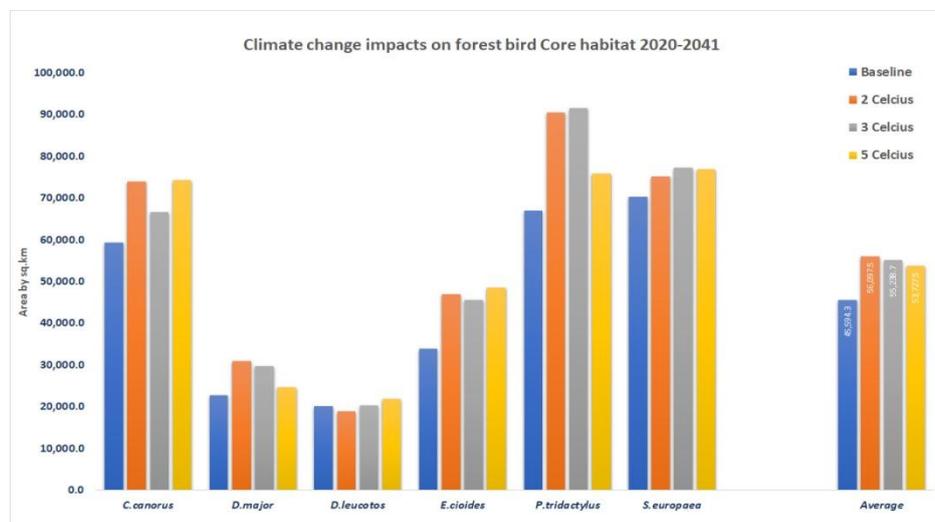


Figure 2. Climate change impacts on forest bird Core habitat 2021-2040

Medium-term climate change scenario (2041-2060) in Range Habitat

In the medium-term climate change, the Range habitat of the six bird species in the 2000 baseline is projected to increase by 15.0%, 12.3% and 11.6% to 341,376.1 sq.km (avg=44,568.1 sq.km), 333,446.9 sq.km (avg=36,638.9 sq.km) and 331,296.9 sq.km (avg=34,489.0 sq.km) in that order, based on a projected average future warming of +2, +3 and +5°C (around 2050) (Figure 3). For

each species, the average Range habitat of the Common Cuckoo (*Cuculus canorus*) is expected to decrease by -8,409.5 sq.km, the Great Spotted Woodpecker (*Dendrocopos major*) by 68,675.5 sq.km, the White-backed Woodpecker (*Dendrocopos leucotos*) by -8,764.5 sq.km, the Meadow Bunting (*Emberiza cioides*) by 70,150.0 sq.km, the Eurasian Three-toed Woodpecker (*Picoides tridactylus*) by 81,815.9 sq.km, and the Eurasian Nuthatch (*Sitta europaea*) by 27,924.7 sq.km.

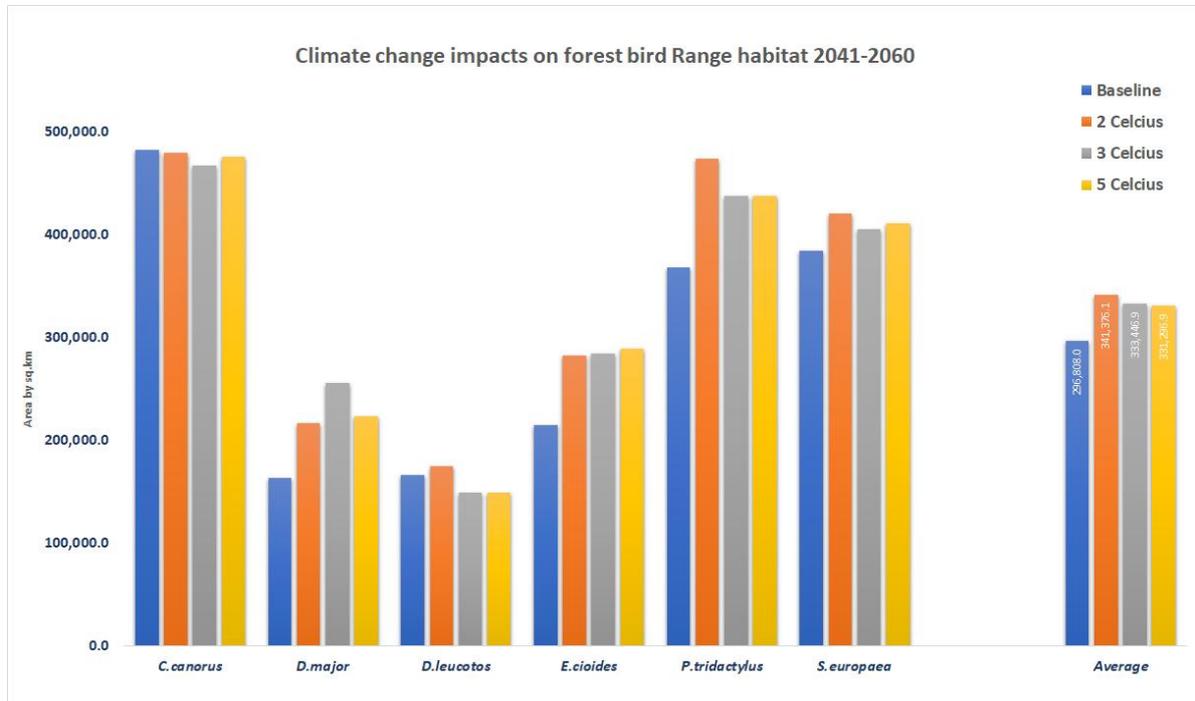


Figure 3. Climate change impacts on forest bird Range habitat 2061-2080

Medium-term climate change scenario (2041-2060) in the Core habitat

Over the medium-term climate change, the Core habitat of six bird species will increase by an average of 25.6%, 16%, and 20.9% from the base year average (avg=45,594.3 sq.km) to 57,250.5 sq.km (avg=11,656.2 sq.km), 52,888.4 sq.km (avg=7,294.1 sq.km), and 55,102.7 sq.km (avg=9,508.4 sq.km) by 2050, respectively, under a projected warming of +2, +3, and +5 degrees Celsius

(Figure 4). For each species, the average range of +2, +3 and +5 °C changes (n=3) around 2050 is expected to increase by 7,531.9 sq.km for the Common Cuckoo (*Cuculus canorus*), 10,058.7 sq.km for the Great Spotted Woodpecker (*Dendrocopos major*), 1068.2 sq.km for the White-backed Woodpecker (*Dendrocopos leucotos*), 17,233.3 sq.km for the Meadow Bunting (*Emberiza cioides*), 14,375.9 sq.km for the Eurasian Three-toed Woodpecker (*Picoides tridactylus*), and 8,758.8 sq.km for the Eurasian Nuthatch (*Sitta europaea*).

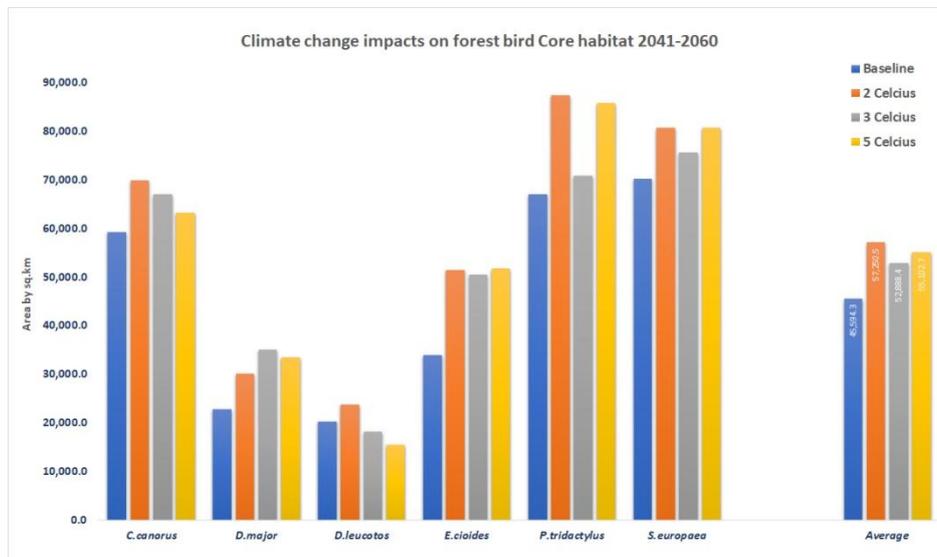


Figure 4. Climate change impacts on forest bird Core habitat 2041-2060

Long-term climate change scenario (2061-2080) in Range Habitat

The six bird species Range habitat in the long-term climate change scenario is projected to increase by +2, +3 and +5 degrees Celsius from the 2000 average to 326,275.2 sq.km (avg=29,467.2 sq.km), 320,938.6 sq.km (avg=24,130.6 sq.km) and 336,775.7 sq.km (avg=39,967.7 sq.km) by 2070, respectively, representing an increase of 9.9%, 8.1% and 13.5% from the base year average

(Figure 5). For each species, the Range habitat of the Common Cuckoo (*Cuculus canorus*) is expected to decrease by -8,409.5 sq.km, the Great Spotted Woodpecker (*Dendrocopos major*) by 68,675.5 sq.km, the White-backed Woodpecker (*Dendrocopos leucotos*) by -6,389.7 sq.km, the Meadow Bunting (*Emberiza cioides*) by 70,150.0 sq.km, the Eurasian Three-toed Woodpecker (*Picoides tridactylus*) by 81,815.9 sq.km, and the Eurasian Nuthatch (*Sitta europaea*) by 27,924.7 sq.km, respectively, under average changes of +2, +3, and +5 degrees Celsius by 2070.

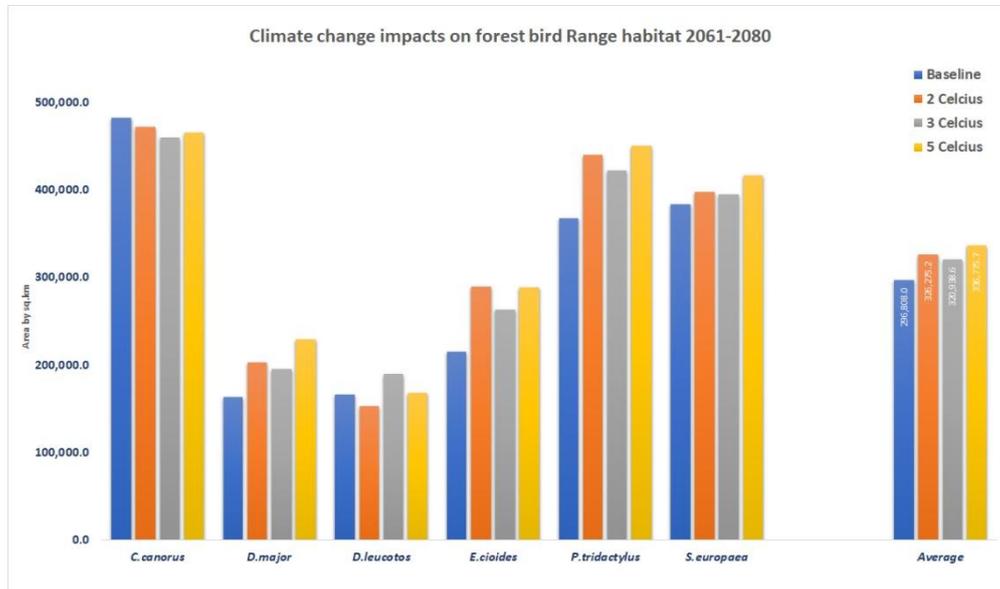


Figure 5. Climate change impacts on forest bird Range habitat 2061-2080

Long-term climate change scenario (2061-2080) in the Core habitat

In the long-term, climate change, the average Core habitat (avg=45,594.3 sq.km) of the six species is projected to increase by 18.2%, 13.2%, and 23.4% from the baseline, to 53,904.4 sq.km (avg=8,310.1 sq.km), 51,596.1 sq.km (avg=6,001.8 sq.km), and 56,242.2 sq.km (avg=10,647.9 sq.km), respectively, under the projection of +2, +3, and +5 degrees Celsius warming around 2070

(Figure 6). By species, the core habitat of the Common Cuckoo (*Cuculus canorus*) is expected to increase by 6,882.5 sq.km, the Great Spotted Woodpecker (*Dendrocopos major*) by 4,742.5 sq.km, the White-backed Woodpecker (*Dendrocopos leucotos*) by 3,750.4 sq.km, the Meadow Bunting (*Emberiza cioides*) by 14,239.9 sq.km, the Eurasian Three-toed Woodpecker (*Picoides tridactylus*) by 15,437.9 sq.km, and the Eurasian Nuthatch (*Sitta europaea*) by 4,866.5 sq.km, respectively, under average changes of +2, +3, and +5 degrees Celsius (n=3) by 2070.

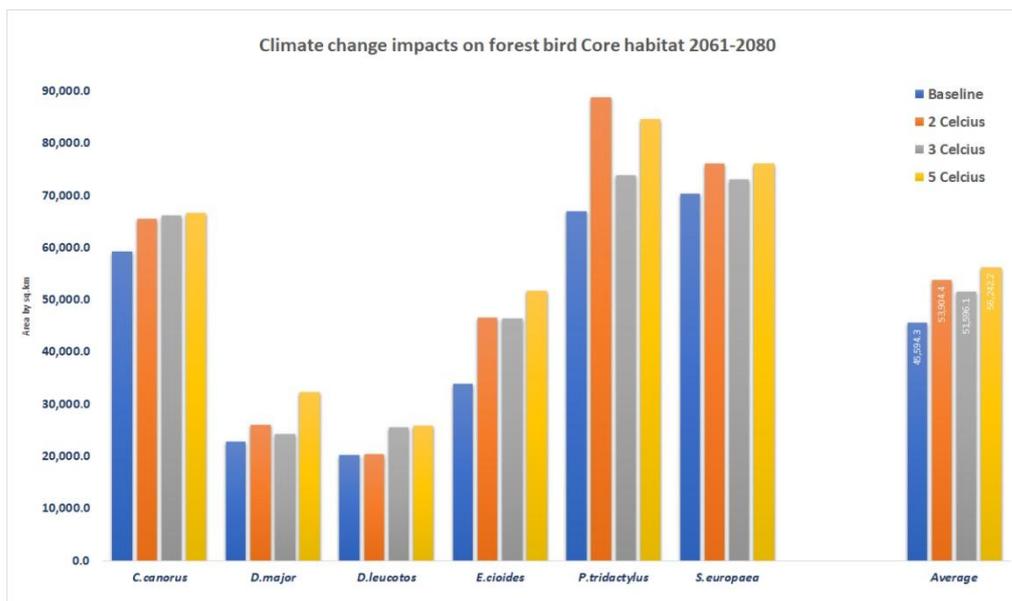


Figure 6. Climate change impacts on forest bird Core habitat 2061-2080

Long-term climate change scenario (2081-2100) in Range Habitat

In the long-term climate change scenario, around 2090, the Range habitat of 6 bird species is projected to be 321,645.3 sq.km (avg=24,837.3 sq.km), 349,114.0 sq.km (avg=52,306.0 sq.km) and 277,939.2 sq.km (avg=-18,868.8 sq.km) in the order of +2 and +3 degrees Celsius warming, respectively, increasing by 8.4% and 17.6% from the base year average, while decreasing by -6.4% in the +5 scenario (Figure 7). For each species, the average range

habitat of the Common Cuckoo (*Cuculus canorus*) is expected to decrease by -27,675.8 sq.km, the Great Spotted Woodpecker (*Dendrocopos major*) by 94,721.7 sq.km, the White-backed Woodpecker (*Dendrocopos leucotos*) by -19,765.0 sq.km, the Meadow Bunting (*Emberiza cioides*) by -21,374.7 sq.km, the Eurasian Three-toed Woodpecker (*Picoides tridactylus*) by 71,810.5 sq.km, and the Eurasian Nuthatch (*Sitta europaea*) by 18,832.3 sq.km, respectively, under the average of +2, +3, and +5 degrees Celsius (n=3) changes around 2090.

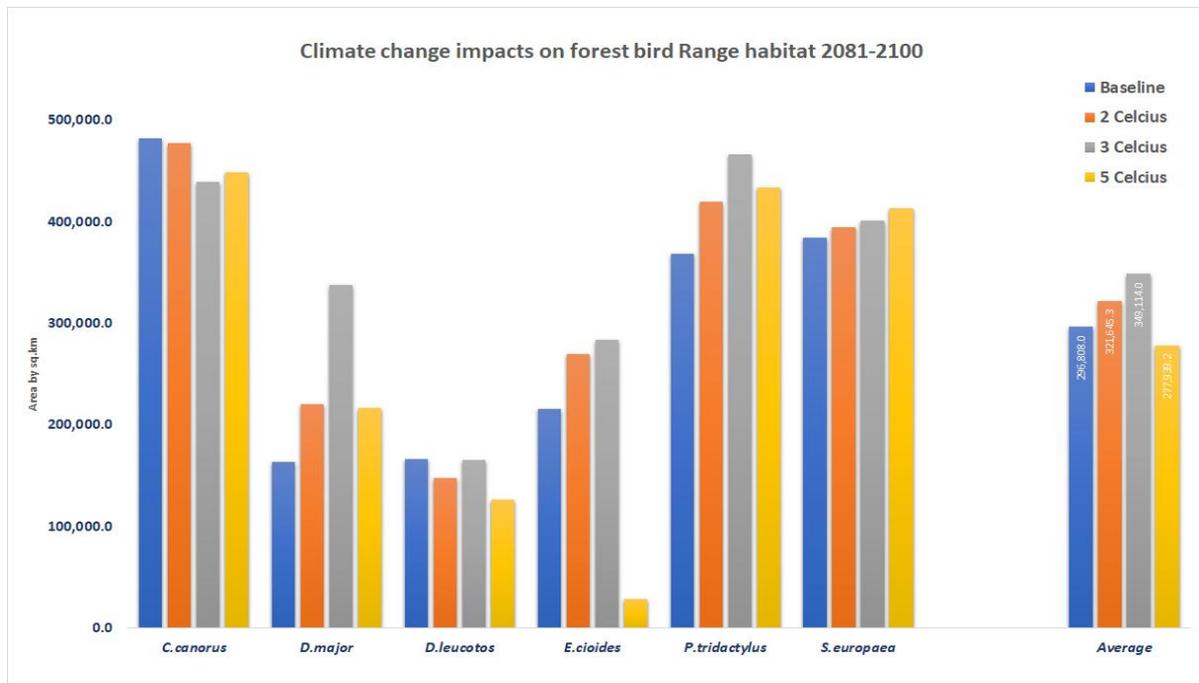


Figure 7. Climate change impacts on forest bird Range habitat 2081-2100

Long-term climate change scenario (2081-2100) in the core habitat

In the long-term climate change scenario, the average Core habitat (avg=45,594.3 sq.km) of the six species in the baseline increased by 16.9%, 26%, and 14.5%, respectively, to 53,316.1 sq.km (avg=7,721.7 sq.km), 57,432.2 sq.km (avg=11,837.9 sq.km), and 52,197.2 sq.km (avg=6,602.9 sq.km) under the projection of +2, +3, and +5 degrees Celsius warming around 2090 (Figure 8). For each species, the Core habitat average (n=3) of the Common

Cuckoo (*Cuculus canorus*) is expected to increase by 2,746.7 sq.km, the Great Spotted Woodpecker (*Dendrocopos major*) by 17,688.7 sq.km, the White-backed Woodpecker (*Dendrocopos leucotos*) by -784.8 sq.km, the Meadow Bunting (*Emberiza cioides*) by 14,700.1 sq.km, the Eurasian Three-toed Woodpecker (*Picoides tridactylus*) by 16,562.7 sq.km, and the Eurasian Nuthatch (*Sitta europaea*) by 1,411.4 sq.km, respectively, under the average (n=3) of changes of +2, +3, and +5 degrees Celsius by 2090.

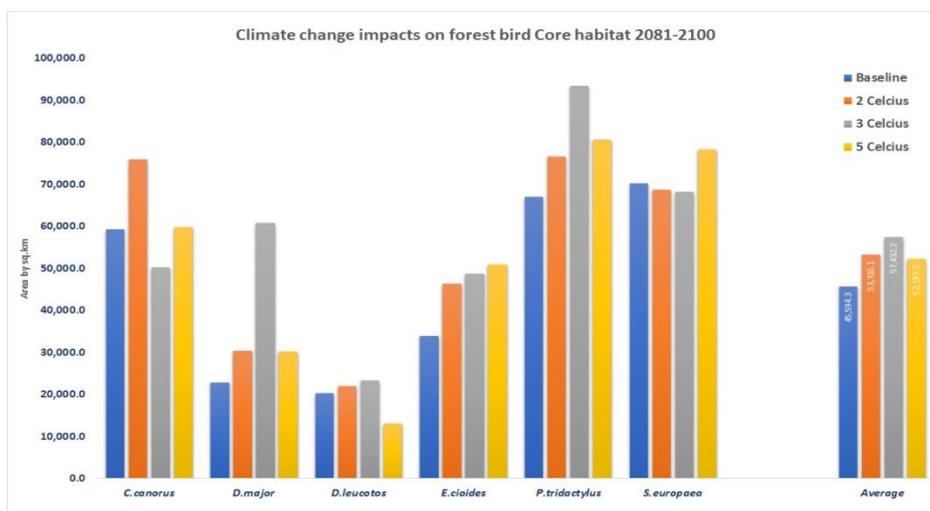


Figure 8. Climate change impacts on forest bird Core habitat 2081-2100

There is no statistical significance observed between the changes in the range habitat of six representative forest bird species (Figures 1, 3; 5; 7; 10) under future climate change modeling. The modeling shows that the average range habitat of 6 bird species (n=6) is projected to change by 30%, 25.5%, and 29.5% under a +2°C warming scenario from baseline to 2030 (2021-2040) and between 2030 and 2050 (2041-2060) under a +2°C warming scenario, while it is projected to increase by 1% under a +3°C warming scenario, by 2.3%, and by -1.5% under a +5°C warming scenario, and then by -4.4% under a +2°C warming scenario, by -3.8% under a +3°C warming scenario, and by 1.7% under a +5°C warming scenario, from 2050 (2041-2060) to 2070 (2061-2080). Around 2090 from 2070 (2081-2100), it is -1.4% lower for +2 degrees Celsius warming, 8.8% higher for +3 degrees Celsius, and -17.5% lower for +5 degrees Celsius.

Comparing the changes in each of the four future climate change scenario periods (2030, 2050, 2070 and 2090) with the base 2000

year, the average range habitat (n=6) is expected to increase by 30.2% for a warming of +2°C, 25.5% for a warming of +3°C, 29.5%, for a warming of +5°C around 2030, 31.5% for a warming of +2°C, 28.4% for a warming of +3°C, 27.6% for a warming of +5°C around 2050, 25.7% for a warming of +2°C, 23.6% for a warming of +3°C, 29.7% for a warming of +5°C around 2070, and 23.9% for a warming of +2°C, 34.5% for a warming of +3°C, and 7.1% for a warming of +5°C around 2090. The average range habitat size (n=6) of these 6 bird species will be changed relatively evenly and slightly in the near, medium, and long term due to climate change in the future (Figures 1, 3; 5; 7; 10; Tables 1; 4). Among the six forest bird species, the comparison of the baseline 2000 and the four future change scenarios of +2, +3, and +5 degrees shows that the Common Cuckoo (*Cuculus canorus*) and the Eurasian Three-toed Woodpecker (*Picoides tridactylus*) are statistically significantly different in their range habitat change ($df-1; f=12.003; p=0.00201$).

Table 1. Range habitat changes of 6 bird species (by annual period)

Periods	<i>C.canorus</i>	<i>D.major</i>	<i>D.leucotos</i>	<i>E.cioides</i>	<i>P.tridactylus</i>	<i>S.europaea</i>
Baseline 2000	482,677.1	163,530.7	166,599.3	215,413.1	368,262.2	384,365.5
2021-2040/+2	493,717.1	221,358.7	169,888.8	263,852.0	461,934.1	417,828.7
2021-2040/+3	450,913.3	220,641.3	136,294.6	264,915.6	461,538.6	421,455.0
2021-2040/+5	500,103.2	222,394.6	174,445.6	273,429.4	432,928.0	414,221.8
Baseline 2000	482,677.1	163,530.7	166,599.3	215,413.1	368,262.2	384,365.5
2041-2060/+2	479,601.4	216,968.4	174,566.8	282,515.3	474,269.1	420,335.6
2041-2060/+3	467,360.5	255,975.4	149,243.4	284,532.7	437,861.1	405,708.3
2041-2060/+5	475,840.8	223,674.6	149,694.2	289,641.2	438,104.2	410,826.5
Baseline 2000	482,677.1	163,530.7	166,599.3	215,413.1	368,262.2	384,365.5
2061-2080/+2	472,434.6	203,334.0	153,458.4	289,768.8	440,592.5	398,062.8
2061-2080/+3	460,170.1	195,300.7	189,601.7	262,995.1	422,778.3	394,785.7
2061-2080/+5	466,056.1	229,681.2	168,193.8	288,666.2	450,858.1	417,198.9
Baseline 2000	482,677.1	163,530.7	166,599.3	215,413.1	368,262.2	384,365.5
2081-2100/+2	477,290.5	220,060.2	148,108.4	270,085.2	419,940.9	394,386.5
2081-2100/+3	439,312.6	338,038.0	165,757.6	283,499.7	466,589.9	401,486.3
2081-2100/+5	448,400.8	216,658.9	126,637.0	28,530.5	433,687.2	413,720.6

The comparison of the future climate-induced changes in the range habitat of each six forest bird species for each annual period (by changes 20 years) with the scenarios of +2, +3 and +5 °C shows that in the near future, around 2030, the Common Cuckoo (*Cuculus canorus*) and Eurasian Nuthatch (*Sitta europaea*) ($df-1; f=27.359; p=0.0019$), the White-backed Woodpecker (*Dendrocopos leucotos*) and Meadow Bunting (*Emberiza cioides*) ($df-1; f=34.515; p=0.00107$) and the Great Spotted Woodpecker (*Dendrocopos major*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df-1; f=72.245; p=0.0014$) range habitat change were statistically significant different. While there were statistically significant

differences between the Great Spotted Woodpecker (*Dendrocopos major*) and the White-backed Woodpecker (*Dendrocopos leucotos*) ($df-1; f=7.1651; p=0.0366$) and the Great Spotted Woodpecker (*Dendrocopos major*) and the Meadow Bunting (*Emberiza cioides*) ($df-1; f=5.865; p=0.0517$). In the medium term, around 2050, the differences in the range habitat of Common Cuckoo (*Cuculus canorus*) and Eurasian Nuthatch (*Sitta europaea*) ($df-1; f=73.298; p=0.0001$), Great Spotted Woodpecker (*Dendrocopos major*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df-1; f=53.619; p=0.0003$), White-backed Woodpecker (*Dendrocopos leucotos*) and Meadow Bunting (*Emberiza cioides*) ($df-1;$

$f=33.362$; $p=0.0011$) are statistically significant, while the differences in the range habitat of Common Cuckoo (*Cuculus canorus*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) are statistically significant. Whereas, the difference in the range habitat changes among the six bird species, White-backed Woodpecker (*Dendrocopos leucotos*) and Meadow Bunting (*Emberiza cioides*), is statistically significant around 2070. However, in the long term, there are statistically significant differences in the range habitat changes of Common Cuckoo (*Cuculus canorus*) and Great Spotted Woodpecker (*Dendrocopos major*) ($df-1$; $f=35.152$; $p=0.0010$), Common Cuckoo (*Cuculus canorus*) and Eurasian Nuthatch (*Sitta europaea*) ($df-1$; $f=26.553$; $p=0.0021$), and Meadow Bunting (*Emberiza cioides*) and Eurasian Nuthatch (*Sitta europaea*) around 2090 (Table 1).

Changes in bird Core habitats due to climate change: The impact of future climate change modelling (HadGEM3) on the represented forest birds is clearly evident under warming scenarios (Figures 2, 4, 6, 8, 9). The habitat modeling shows that the average ($n=6$) core habitat of 6 bird species increased by 23%, 21.2%, and 17.8% under the +2°C, +3°C and +5°C warming scenario from 2000 to 2030, while it increased by 2.1%, decreased by -4.3%, and 2.6% under the +2°C, +3°C and +5°C warming scenario from 2030

to 2050, whereas it decreased by -5.8%, -2.4%, and increased 2.1% under the +2°C, +3°C and +5°C warming scenario from 2050 to 2070, and it decreased by -1.1%, increased by 11.3%, and 7.2% under the +2°C, +3°C and +5°C warming scenario from 2070 to 2090.

Comparing the changes in each of the four future climate change periods (2030, 2050, 2070 and 2090) with the base year of 2000, the average of the core habitat ($n=6$) is expected to increase and expand by +2°C by 23%, +3°C by 21.2%, and +5°C by 17.8% around 2030, by +2°C by 25.6%, +3°C by 16%, and +5°C by 2050, by +2°C by 18.2%, +3°C by 13.2%, and +5°C by 23.4% around 2070, and by +2°C by 16.9%, +3°C by 26%, and +5°C by 14.5% around 2090. The average core habitat of six bird species is expected to decrease in the long term, around 2090, due to future climate change. The modeling scenario suggests that the largest changes in core habitat will appear in the near term, around 2030. When comparing the baseline year 2000 and the four future scenarios with +2, +3, and +5 degrees Celsius changes, the Common Cuckoo (*Cuculus canorus*) and Eurasian Nuthatch (*Sitta europaea*) ($df-1$; $f=16.381$; $p=0.0004$) are statistically significantly different from the others in terms of range changes.

Table 2. Core habitat changes of 6 bird species (by annual period)

Periods	<i>C.canorus</i>	<i>D.major</i>	<i>D.leucotos</i>	<i>E.cioides</i>	<i>P.tridactylus</i>	<i>S.europaea</i>
Baseline 2000	59,269.9	22,795.9	20,214.6	33,967.4	67,018.5	70,299.6
2021-2040/+2	73,998.0	30,884.7	19,001.4	46,899.9	90,548.0	75,253.1
2021-2040/+3	66,683.9	29,805.6	20,379.7	45,557.4	91,638.6	77,367.0
2021-2040/+5	74,318.5	24,746.0	21,879.2	48,485.2	75,921.7	77,014.2
Baseline 2000	59,269.9	22,795.9	20,214.6	33,967.4	67,018.5	70,299.6
2041-2060/+2	70,002.4	30,089.1	23,768.2	51,448.4	87,438.7	80,756.3
2041-2060/+3	67,081.9	35,042.7	18,223.1	50,441.9	70,910.9	75,630.0
2041-2060/+5	63,320.9	33,512.9	15,447.9	51,711.8	85,833.7	80,789.1
Baseline 2000	59,269.9	22,795.9	20,214.6	33,967.4	67,018.5	70,299.6
2061-2080/+2	65,510.0	26,016.2	20,471.9	46,535.9	88,776.3	76,116.3
2061-2080/+3	66,240.2	24,323.0	25,543.9	46,421.7	73,876.0	73,172.2
2061-2080/+5	66,706.8	32,276.0	25,879.2	51,664.5	84,717.0	76,210.0
Baseline 2000	59,269.9	22,795.9	20,214.6	33,967.4	67,018.5	70,299.6
2081-2100/+2	75,950.8	30,366.7	21,929.3	46,406.0	76,605.9	68,637.6
2081-2100/+3	50,241.7	60,824.1	23,235.6	48,676.9	93,468.3	68,146.5
2081-2100/+5	59,857.2	30,263.1	13,124.6	50,919.6	80,669.5	78,349.1

The average Core habitat changes of six bird species are statistically significantly different ($df-3$, $f=5.7823$; p -value 0.005137) under the scenarios of future climate change of +2°C in each year from 2030 to 2050, 2070, and 2090. However, the differences in core habitat changes between the scenarios of +3°C

($df-3$, $f=0.8132$; p -value 0.2015) and +5°C ($df-3$, $f=2.0492$; p -value 0.1393) are not statistically significant (Table 2).

Comparing the percentage of climate-induced changes around 2030 with the averages of the six species' ranges for 2050, 2070, and 2090, the difference in core habitat changes between 2030 and 2090 ($df-3$, $f=4.7777$; p -value 0.0537) is statistically significant,

and the differences between 2030 and 2050 ($df=3, f=3.9189$; p -value 0.0759) and 2030 and 2070 ($df=3, f=3.9189$; p -value 0.07591) are clearly significant (Tables 2; 3).

In the core habitat, comparing the 6 bird species under the +2, +3 and +5 °C scenarios of future climate change impacts over the year (by 20 years), the following are expected to be the most likely to occur in the near future, around 2030: Common Cuckoo (*Cuculus canorus*) and Meadow Bunting (*Emberiza cioides*) ($df=1; f=26.083$; $p=0.00220$), Great Spotted Woodpecker (*Dendrocopos major*) and

White-backed Woodpecker (*Dendrocopos leucotos*) ($df=1; f=10.765$; $p=0.0168$), Meadow Bunting (*Emberiza cioides*) ($df=1; f=18.837$; $p=0.0048$), Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df=1; f=74.909$; $p=0.0001$), White-backed Woodpecker (*Dendrocopos leucotos*) and Meadow Bunting (*Emberiza cioides*) ($df=1; f=48.328$; $p=0.0004$) and Brown-eared Meadow Bunting (*Emberiza cioides*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df=1; f=30.405$; $p=0.0014$) changes were statistically significant.

Table 3. Changes in the Core habitat of 6 bird species due to climate change (year by year).

species	Base 2000	2030 (2021-2040)			2050 (2041-2060)			2070 (2061-2080)			2090 (2081-2100)		
		2 celcius	3 celcius	5 celcius	2 celcius	3 celcius	5 celcius	2 celcius	3 celcius	5 celcius	2 celcius	3 celcius	5 celcius
<i>C.canorus</i>		24.8	12.5	25.4	-5.4	0.6	-14.8	-6.4	-1.3	5.3	15.9	-24.2	-10.3
<i>D.major</i>		35.5	30.7	8.6	-2.6	17.6	35.4	-13.5	-30.6	-3.7	16.7	150.1	-6.2
<i>D.leucotos</i>	Per cent	-6.0	0.8	8.2	25.1	-10.6	-29.4	-13.9	40.2	67.5	7.1	-9.0	-49.3
<i>E.cioides</i>	%	38.1	34.1	42.7	9.7	10.7	6.7	-9.5	-8.0	-0.1	-0.3	4.9	-1.4
<i>P.tridactylus</i>		35.1	36.7	13.3	-3.4	-22.6	13.1	1.5	4.2	-1.3	-13.7	26.5	-4.8
<i>S.europaee</i>		7.0	10.1	9.6	7.3	-2.2	4.9	-5.7	-3.2	-5.7	-9.8	-6.9	2.8
<i>C.canorus</i>	59,269.9	73,998.0	66,683.9	74,318.5	70,002.4	67,081.9	63,320.9	65,510.0	66,240.2	66,706.8	75,950.8	50,241.7	59,857.2
<i>D.major</i>	22,795.9	30,884.7	29,805.6	24,746.0	30,089.1	35,042.7	33,512.9	26,016.2	24,323.0	32,276.0	30,366.7	60,824.1	30,263.1
<i>D.leucotos</i>	20,214.6	19,001.4	20,379.7	21,879.2	23,768.2	18,223.1	15,447.9	20,471.9	25,543.9	25,879.2	21,929.3	23,235.6	13,124.6
<i>E.cioides</i>	33,967.4	46,899.9	45,557.4	48,485.2	51,448.4	50,441.9	51,711.8	46,535.9	46,421.7	51,664.5	46,406.0	48,676.9	50,919.6
<i>P.tridactylus</i>	67,018.5	90,548.0	91,638.6	75,921.7	87,438.7	70,910.9	85,833.7	88,776.3	73,876.0	84,717.0	76,605.9	93,468.3	80,669.5
<i>S.europaee</i>	70,299.6	75,253.1	77,367.0	77,014.2	80,756.3	75,630.0	80,789.1	76,116.3	73,172.2	76,210.0	68,637.6	68,146.5	78,349.1

In the medium-term, around 2050, there are significant differences between Great Spotted Woodpecker (*Dendrocopos major*) and White-backed Woodpecker (*Dendrocopos leucotos*) ($df=1; f=11.420$; $p=0.0148$), Meadow Bunting (*Emberiza cioides*) ($df=1; f=10.485$; $p=0.0177$), and while White-backed Woodpecker (*Dendrocopos leucotos*) and Meadow Bunting (*Emberiza cioides*) ($df=1; f=34.798$; $p=0.0010$), and Meadow Bunting (*Emberiza cioides*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df=1; f=21.042$; $p=0.0037$), and the Eurasian Nuthatch (*Sitta europaee*) ($df=1; f=36.086$; $p=0.0009$) is statistically significant.

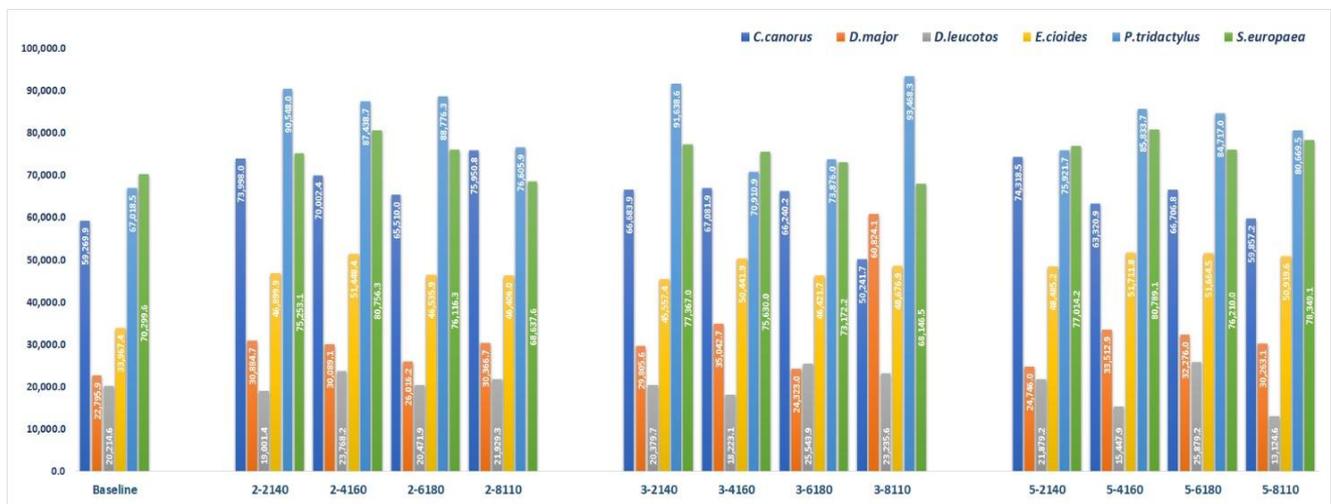


Figure 9. Climate change impacts on the forest birds' Core habitat

In the long-term, around 2070, there are significant differences between Common Cuckoo (*Cuculus canorus*) and Meadow Bunting (*Emberiza cioides*) ($df=1; f=22.771$; $p=0.0030$), Eurasian Nuthatch (*Sitta europaee*) ($df=1; f=18.123$; $p=0.0053$), Great Spotted Woodpecker (*Dendrocopos major*) and Brown-eared Bunting (*Emberiza cioides*) ($df=1; f=18.092$; $p=0.0053$), and Eurasian Nuthatch (*Sitta europaee*) ($df=1; f=53.179$; $p=0.0003$). However, around 2090, there were statistically significant differences in the core habitat of Common Cuckoo (*Cuculus canorus*) and White-backed Woodpecker (*Dendrocopos leucotos*) ($df=1; f=51.649$; $p=0.0003$), Great Spotted Woodpecker (*Dendrocopos major*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df=1; f=18.571$; $p=0.0050$), Eurasian Nuthatch (*Sitta europaee*) ($df=1; f=16.197$; $p=0.0069$), White-backed Woodpecker (*Dendrocopos leucotos*) and Meadow Bunting (*Emberiza cioides*) ($df=1; f=33.110$; $p=0.0011$), Eurasian Nuthatch (*Sitta europaee*) ($df=1; f=18.571$; $p=0.0050$) and Meadow Bunting (*Emberiza cioides*) and Eurasian Three-toed Woodpecker (*Picoides tridactylus*) ($df=1; f=26.722$; $p=0.0020$) (Table 2).

Table 4. Climate change impacts on the forest bird Range habitat

Species	Base 2000	2030 (2021-2040)			2050 (2041-2060)			2070 (2061-2080)			2090 (2081-2100)			
		2 celcius	3 celcius	5 celcius	2 celcius	3 celcius	5 celcius	2 celcius	3 celcius	5 celcius	2 celcius	3 celcius	5 celcius	
C.canorus		2.3	-6.6	3.6	-0.6	-3.2	-1.4	-2.1	-4.7	-3.4	-1.1	-9.0	-7.1	
D.major		35.4	34.9	36.0	32.7	56.5	36.8	24.3	19.4	40.5	34.6	106.7	32.5	
D.leucotos	Per cent %	2.0	-18.2	4.7	4.8	-10.4	-10.1	-7.9	13.8	1.0	-11.1	-0.5	-24.0	
E.cioides		22.5	23.0	26.9	31.2	32.1	34.5	34.5	22.1	34.0	25.4	31.6	-86.8	
P.tridactylus		25.4	25.3	17.6	28.8	18.9	19.0	19.6	14.8	22.4	14.0	26.7	17.8	
S.europaea		8.7	9.6	7.8	9.4	5.6	6.9	3.6	2.7	8.5	2.6	4.5	7.6	
C.canorus		482,677.1	493,717.1	450,913.3	500,103.2	479,601.4	467,360.5	475,840.8	472,434.6	460,170.1	466,056.1	477,290.5	439,312.6	448,400.8
D.major		163,530.7	221,358.7	220,641.3	222,394.6	216,968.4	255,975.4	223,674.6	203,334.0	195,300.7	229,681.2	220,060.2	338,038.0	216,658.9
D.leucotos	166,599.3	169,888.8	136,294.6	174,445.6	174,566.8	149,243.4	149,694.2	153,458.4	189,601.7	168,193.8	148,108.4	165,757.6	126,637.0	
E.cioides	215,413.1	263,852.0	264,915.6	273,429.4	282,515.3	284,532.7	289,641.2	289,768.8	262,995.1	288,666.2	270,085.2	283,499.7	28,530.5	
P.tridactylus	368,262.2	461,934.1	461,538.6	432,928.0	474,269.1	437,861.1	438,104.2	440,592.5	422,778.3	450,858.1	419,940.9	466,589.9	433,687.2	
S.europaea	384,365.5	417,828.7	421,455.0	414,221.8	420,335.6	405,708.3	410,826.5	398,062.8	394,785.7	417,198.9	394,386.5	401,486.3	413,720.6	

The western and eastern regions of Mongolia are projected to be 5.5-7.5⁰C, while the western region is projected to be 5.0-5.5⁰C in the summer. Winter precipitation is projected to increase by 55-75% in the central, western, and eastern regions, while summer precipitation is projected to decrease by 5-10% in the western region and increase slightly in other regions (Dagvadorj et al., 2014).

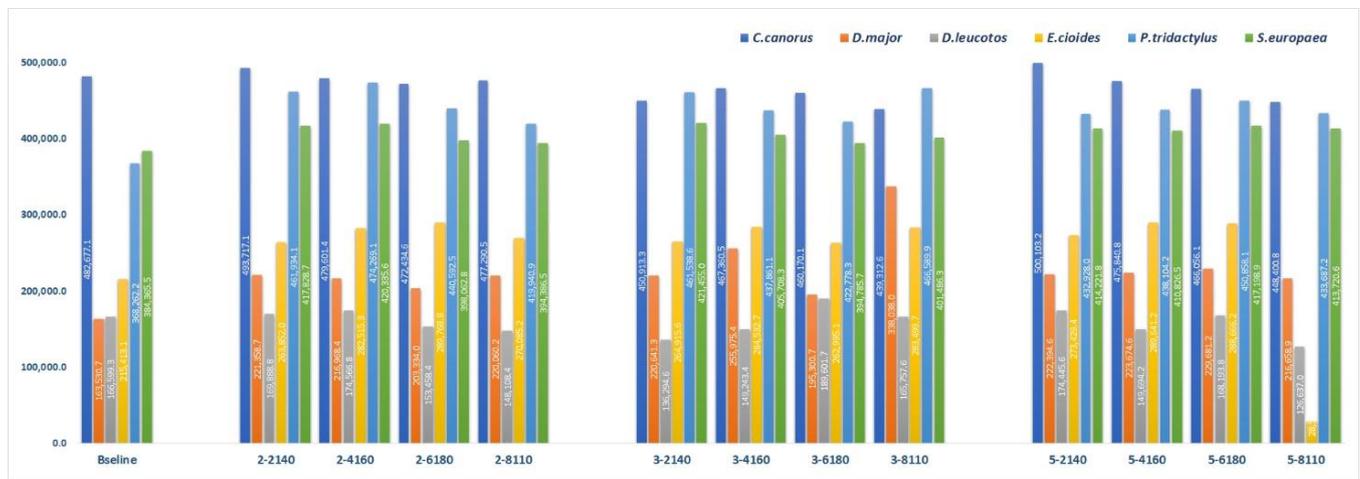


Figure 10. Climate change impacts on the forest bird Range habitat

Climate change impacts on forest birds and their food sources

The impacts of future climate change (2030, 2050, 2070 and 2090) on forest birds such as Common Cuckoo (*Cuculus canorus*), Great Spotted Woodpecker (*Dendrocopos major*), White-backed Woodpecker (*Dendrocopos leucotos*), Meadow Bunting (*Emberiza cioides*), Eurasian Three-toed Woodpecker (*Picoides tridactylus*), Eurasian Nuthatch (*Sitta europaea*) and the pest insects that overlapping their ranges and feed on, such as Siberian silk moth (*Dendrolimus sibiricus*), Jacobson's spanworm (*Erannis jacobsoni*), Gypsy moth (*Lymantria dispar*), and while the Cowberry (*Vaccinium vitis-idaea*), Bog bilberry (*Vaccinium uliginosum*) and Black Currant (*Ribes nigrum*) were selected from the natural berry species for analyzys by individually and mutually with representatives of the food-dependent species, or as a unified and comprehensive assessment of the ecosystem. Future climate change will affect the habitats of bird species.

When looking at the range habitat changes in all 12 species of birds, insects, and plants together, or in terms of biodiversity, in the future, with a warming of +2°C, the difference in change from the baseline around 2030 is on average (n=12) 21,563.4 sq.km (SE 8,860.2; kurt 1.4; CL95% 14,542.5), around 2050 is on average 23,070.6 sq.km (SE 10,201.1; kurt 1.4; CL95% 22,452.5), around 2070 is on average 9,814.0 sq.km (SE 11,169.2; Kurt 0.9; CL95% 24,583.2) and around 2090 is on average 14,328.0 sq.km (SE 7,426.5; Kurt -0.7; CL95% 16,345.6) area is expected to be increased. For natural berry species, the distribution area is decreasing or slightly disappearing. The average change for each species around 2030-2090 varies (Table 5).

Table 5. Changes in species range habitat (sq.km) due to +2°C warming effects

Species'	2030	2050	2070	2090	Mean	SEError	SDeviation	Kurtosis	Conf.Level (95.0%)
<i>C.canorus</i>	11,040.0	-3,075.6	-	-5,386.5	-1,916.1	4,569.6	9,139.2	2.3	14,542.6
<i>D.major</i>	57,828.0	53,437.8	39,803.3	56,529.5	51,899.7	4,135.9	8,271.8	3.0	13,162.3

<i>D.leucotos</i>	3,289.5	7,967.4	-13,140.9	-18,490.9	-5,093.7	6,358.2	12,716.3	-4.5	20,234.5
<i>E.cioides</i>	48,438.8	67,102.2	74,355.7	54,672.0	61,142.2	5,869.1	11,738.2	-3.0	18,678.1
<i>P.tridactylus</i>	93,671.9	106,006.9	72,330.3	51,678.7	80,922.0	11,975.0	23,949.9	-1.8	38,109.7
<i>S.europaea</i>	33,463.3	35,970.1	13,697.3	10,021.1	23,287.9	6,660.6	13,321.2	-5.5	21,197.1
<i>D.sibiricus</i>	1,158.1	747.9	2,355.8	11,863.7	4,031.4	2,633.0	5,265.9	3.6	8,379.3
<i>E.jacobsoni</i>	14,167.9	12,013.4	13,743.4	15,368.5	13,823.3	694.5	1,389.1	1.2	2,210.3
<i>L.dispar</i>	1,259.1	1,766.3	3,419.9	2,040.6	2,121.5	462.1	924.2	2.1	1,470.6
<i>V.vitis</i>	264.1	-346.2	-67,414.3	-1,828.6	-17,331.2	16,700.1	33,400.3	4.0	53,147.3
<i>V.uliginosum</i>	-4,358.2	-1,554.1	-5,492.9	1,072.6	-2,583.1	1,473.1	2,946.2	-1.9	4,688.1
<i>R.nigrum</i>	-1,461.4	-3,189.0	-5,647.2	-5,605.1	-3,975.7	1,016.1	2,032.2	-2.7	3,233.6

With a future warming of +3°C scenario, the range habitat is expected to be increased by an average of 15,832.1 sq.km (SE 10,625.3; Kurt 0.3; CL95% 23,386.1) around 2030, by an average of 19,094.9 sq.km (SE 10,630.5; Kurt -0.1; CL95% 23,397.5) around 2050, by an average of 18,077.7 sq.km (SE 5,667.8; Kurt -0.1; CL95% 12,628.7) around 2070, and then by an average of 27,813.5 sq.km (SE 16,951; Kurt 2.9; CL95% 37,308.9) around 2090, compared to the baseline year. For natural berry species that are fed by the birds, it is expected to decline or mutually disappear except around 2070 (Table 6).

Table 6. Changes in species range habitat (sq.km) due to +3°C warming effects

Species'	Periods				Mean	SError	SDeviation	Kurtosis	Conf.Level (95.0%)
	2030	2050	2070	2090					
<i>C.canorus</i>	-31,763.8	-15,316.5	-22,507.0	-43,364.5	-28,238.0	6,062.5	12,125.0	-0.9	19,293.6
<i>D.major</i>	57,110.6	92,444.7	31,770.0	174,507.3	88,958.1	31,112.1	62,224.2	1.0	99,012.6
<i>D.leucotos</i>	-30,304.7	-17,355.9	23,002.4	-841.7	-6,375.0	11,499.5	22,999.0	-0.5	36,596.5
<i>E.cioides</i>	49,502.5	69,119.6	47,582.0	68,086.6	58,572.7	5,808.2	11,616.3	-5.8	18,484.2
<i>P.tridactylus</i>	93,276.4	69,598.9	54,516.1	98,327.8	78,929.8	10,268.1	20,536.1	-3.3	32,677.6
<i>S.europaea</i>	37,089.6	21,342.9	10,420.2	17,120.8	21,493.4	5,664.2	11,328.4	1.6	18,026.0
<i>D.sibiricus</i>	635.8	1,425.7	2,299.9	9,605.9	3,491.8	2,066.2	4,132.3	3.5	6,575.4
<i>E.jacobsoni</i>	11,940.9	8,932.7	11,812.3	12,554.3	11,310.0	808.8	1,617.6	3.3	2,574.0
<i>L.dispar</i>	1,559.4	2,657.7	4,512.0	3,549.1	3,069.5	629.9	1,259.7	-0.8	2,004.5
<i>V.vitis</i>	5,968.4	3,846.2	8,040.9	-131.2	4,431.1	1,745.3	3,490.5	0.2	5,554.2
<i>V.uliginosum</i>	-3,197.0	-2,999.3	3,793.4	-1,880.1	-1,070.8	1,647.1	3,294.2	3.3	5,241.8
<i>R.nigrum</i>	-1,832.8	-4,557.7	1,105.8	-3,771.7	-2,264.1	1,260.8	2,521.6	-0.2	4,012.4

With a future warming of +5°C, the range habitat is expected to be increased by an average of 21,011.2 sq.km (SE 7,299.7; Kurt -0.8; CL95% 16,066.6) around 2030, by an average of 19,105.6 sq.km (SE 9,047.5; Kurt -0.6; CL95% 19,913.5) around 2050, by an average of 21,831.6 sq.km (SE 9,607.7; Kurt -0.6; CL95% 21,263.1) around 2070, and by an average of -7,353.4 sq.km (SE 18,519.5; Kurt 6.1; CL95% 40,761.1) around 2090, compared to the baseline. In terms of berry species, the species other than Bog bilberry (*Vaccinium uliginosum*) are increasingly around 2070 (Table 7).

Table 6. Changes in species range habitat (sq.km) due to +5°C warming effects

Species'	Periods				Mean	SError	SDeviation	Kurtosis	Conf.Level (95.0%)
	2030	2050	2070	2090					
<i>C.canorus</i>	17,426.2	-6,836.2	-16,621.0	-34,276.3	-10,076.8	10,783.3	21,566.6	0.6	34,317.3
<i>D.major</i>	58,864.0	60,144.0	66,150.5	53,128.2	59,571.7	2,671.3	5,342.5	1.2	8,501.2
<i>D.leucotos</i>	7,846.2	-16,905.2	1,594.5	-39,962.3	-11,856.7	10,741.5	21,483.0	-0.9	34,184.2
<i>E.cioides</i>	58,016.3	74,228.1	73,253.1	-186,882.6	4,653.7	63,953.2	127,906.5	3.9	203,527.8
<i>P.tridactylus</i>	64,665.8	69,842.0	82,595.9	65,425.1	70,632.2	4,148.0	8,295.9	2.3	13,200.7
<i>S.europaea</i>	29,856.4	26,461.1	32,833.4	29,355.1	29,626.5	1,304.8	2,609.6	1.3	4,152.5
<i>D.sibiricus</i>	919.3	2,316.7	-227.6	3,117.5	1,531.5	741.7	1,483.4	-2.2	2,360.4
<i>E.jacobsoni</i>	6,662.4	10,211.8	7,984.1	14,640.4	9,874.7	1,749.3	3,498.5	0.6	5,566.9

<i>L. dispar</i>	2,743.3	4,747.8	4,269.7	1,173.0	3,233.4	809.0	1,617.9	-1.6	2,574.5
<i>V.vitis</i>	1,897.5	258.4	4,438.9	5,482.1	3,019.2	1,188.9	2,377.8	-3.0	3,783.6
<i>V.uliginosum</i>	1,038.6	975.1	3,013.8	-1,064.9	990.6	832.7	1,665.5	1.5	2,650.1
<i>R.nigrum</i>	2,198.7	3,824.0	2,694.2	1,623.7	2,585.1	467.3	934.6	0.6	1,487.1

In recent years, due to intensive human activities and the impact of climate change in forest areas, species have been displaced, moved to other areas, and shifted, altering ecological processes, compromising ecosystem resilience, and threatening ecosystem services and human impacts (Cardinale, B.J. et al, 2012; Soliveres, S. et al, 2016).

The impact of future climate change on the distribution of forest bird species and biodiversity is evident and plausible in Mongolia's forested areas under the selected HadGEM3-GC31-LL scenario (www.worldclim.org/data/cmip6/cmip6_clim30s.html). For the six forest bird species (n=6), the average results from scenarios projecting future warming of +2, +3, and +5 degrees Celsius around 2030, 2050, 2070, and 2090—compared to the average of each year from 2030 to 2090—show that climate change's effect on these species in Mongolia's forests is real and clear. Moving forward, a more detailed study of climate change impacts on biodiversity and ecosystems, either broadly or species-specifically, is essential. This research demonstrates an opportunity to develop scientifically grounded conclusions and recommendations for shaping national strategies and policies related to environmental and socio-economic development. These should focus on the most vulnerable birds, their habitats, and prey, helping to reduce, mitigate, and adapt to the impacts. As biodiversity and environmental research inform climate change adaptation strategies worldwide at all levels, modeling studies of specific locations and species in our country's forests serve as models and emphasize the need for further development.

Conclusion

1. The diversity of forest birds in the Khangai and Khentii Mountain Regions was assessed by compiling data on their habitat distribution in forests and forest-steppe zones, as well as information on some harmful pest insects, plants, and natural fruits that are part of their diet, along with how these resources are used. The habitat and distribution areas were mapped in detail, and HotSpot analysis was performed to create a dynamic database for monitoring environmental and climate changes.
2. The core habitat and range size of six bird species are expected to be affected by future climate change around 2030, 2050, 2070, and 2090. The habitats and distributions of 12 species, including birds, harmful pest insects, and natural fruits, are projected to expand both in the near and distant future due to climate change. The effects of climate change on the habitat and distribution of each bird, insect, and fruit species will vary. Overall, climate change is expected to significantly impact biodiversity.
3. It was confirmed that the effects of climate change are a fact and that it is possible to plan and implement scientifically-based measures to prevent and mitigate these impacts, as well as to assess the level of ecosystem services, through birds that are widely distributed and

can serve as indicators across forested areas throughout Mongolia.

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REFERENCES

1. Bold A. 1997. Biodiversity Bogdkhan Mountain: Avian. Proceedings of Academician A.Bold. Volume II. Compiled by G.Mainjargal & B. Batzol. 2016. 77-80.
2. Bold A. 2003. About Forest Birds. Proceedings of Academician A.Bold. Volume II. Compiled by G.Mainjargal & B. Batzol. 2016. 295-304.
3. Bold A., Dulamtseren S. 1974. A brief overview of the mammal and bird fauna of the Batkhan and Khugnuhan mountains. In Russian. Proceedings of Academician A.Bold. Volume I. Compiled by G.Mainjargal & B. Batzol. 2016. 117-180.
4. Environmental Database. www.eic.mn. The Ministry of Environment and Climate Change (MECC) and the Information and research institute of meteorology, hydrology, and environment.
5. Dorjsuren Ch, Dugarjav Ch, Tsedendash G, Tushigmaa G, Tungalag M. 2020. Forest Zones and Typology of Mongolia. Ulaanbaatar. 74p.
6. Jantsantomboo Kh. 2003. Harmful pest of Mongolia. Ulaanbaatar. 210 p.
7. Atlas of Beneficial Plant Distribution and Resources. Dugarjav Ch. (Ed.In Chief). Ulaanbaatar. 2014.
8. Field Research Report of Mongolia-Germany Joint Expedition. 1962-1964. Unpublished materials.
9. Field Research Report of Mongolia-Russian Joint Biological Expedition. 1983; 1985 & 1999-2001. Unpublished materials.
10. National Atlas of Mongolia. 1991. Vorobyov V.V (Ed. In Chief). Moscow.
11. National Atlas of Mongolia. 2009. Dorjgotov B (Ed. In Chief). Second Edition. Ulaanbaatar.
12. Atlas of Forest Non-Timber Products (Range, Resources & Assessment). Dugarjav Ch. (Ed.In Chief). Ulaanbaatar. 2011.
13. Fomin V.E, Bold A. 1991. Catalogue of birds of the Mongolian People's Republic. Moscow. Nauka. 125p.
14. Khangai. 2010. Samiya R. (Ed.in. Chief). Birds. Ulaanbaatar. 265-275p.
15. Tseveenmyadag N, Bold A, Boldbaatar Sh, Mainjargal G. 2005. Bird Reference of the Khentii Mountainous Region. Ulaanbaatar. 129p.
16. Chuluunbaatar L, Tsedendash G, Tuvshintogtokh I, Manidar D. 2014. Forest and steppe fire danger map of Mongolia. Ministry of Nature, Environmental & Green Development, Mongolia, Institute of Botany MAS, Mongolia-Russia Joint Biological Expedition. Scale 1:1.500.000. Published by the Laboratory of Flora, at the

- Institute of Botany, MAS, under the Scientific Council of the Institute of Botany. Adviser Ch.Dugarjav & Ts,Banzragch.
17. Chuluunbaatar L, Elbegjargal N, Amonjol B. 2017. (Ed. B.Ouynsanaa & Adviser N.Erdenesaikhan) Forest and steppe fire danger distribution map of Mongolia. Scale 1:1.500.000. Geodic reference: UTM Zone 48WFS84. Ministry of Nature, Environmental & Green Development, Mongolia. Developed by the Center of Geo-Database Mongolia under the Science Council Meeting at the Center for Central Asian Fire Management, based on forest and steppe fire data from 2000-2017, with criteria of fire danger.
 18. Fire dangerous Regions. Scale 1:8000.000. Ecosystem of Mongolia. Atlas. General Scientific Edition. (Eds. In Chief. E.A.Vostokova & P.D.Gunin. Maps by Laboratory for ecology of arid areas, Institute of Ecology & Evolution, RAN. 33p: 48pp.
 19. Forest bird habitat changes and diversity of Khangai & Khentii Mountains. 2024. Fundamental survey by the Institute of Biology, MAS. <https://sudalgaa.gov.mn/pdf/khangay-khentiyn-oy-n-shuvuudyn-olon-yanz-baydal-amdrakh-orchny-rchlt-2jm>
 20. Survey on identifying harmful pest insects for combating in Bogdkhan SPA, city green zones, and soums of Dornod, Khentii, and Tuv Aimag (Provinces). 2019. <https://sudalgaa.gov.mn/pdf/dornod-khentiyn-tov-ayngiyn-zarim-sumd-niysleliyn-nogoon-bs-bogdkhan-2mn>
 21. Survey on harmful forest pest insects. 2019. <https://sudalgaa.gov.mn/pdf/oy-n-khortny-sudalgaany-azhil-sbc>
 22. Survey on identifying harmful pest insect distribution, biology & ecology for combating with follow-up and monitoring in Ulaanbaatar city green zones. 2023. <https://sudalgaa.gov.mn/pdf/niysleliyn-nogoon-bsiyn-oy-n-sand-oy-n-khonoolt-shavzhiyn-biologi-ekol-4q9>
 23. Forest bird habitat changes and diversity of Khangai & Khentii Mountains. Fundamental Survey Report. 2022-2024. Institute of Biology, MAS. Ulaanbaatar. 141p.
 24. Batjargal Z, Enkhjargal B. 2013. Interference Impact of Global Warming and Globalization on the Society and Ecosystem in Mongolia. In: *The Mongolian Ecosystem Network, Environmental Issue Under Climate and Social Changes, Springer, Japan. p. 295-313.*
 25. Editors in chief. Dagvadorj D., Z.Batjargal., L.Natsagdorj. 2014. Mongolia second assessment report on Climate Change – 2014. MARCC – 2014. Ulaanbaatar. p.302.
 26. Enkhbileg D., G.Mainjargal. 2025. Impact of Climate Change on Forest Bird Habitats in Mongolia. Conference: 55th Anniversary of the Joint Russian-Mongolian Complex Biological Expedition. At: Chinggis Khaan National Museum, Ulaanbaatar, Mongolia. Proceedings of the Institute of Biology. Abstract. Special Issue. ISSN 2788-9823. (2025):334-335)
 27. Bradley J. Cardinale, J.Emmett Duffy, Andrew Gonzalez, David U. Hooper, Charles Perrings, Patrick Venail1, Anita Narwani, Georgina M. Mace, David Tilman, David A.Wardle, Ann P. Kinzig, Gretchen C. Daily, Michel Loreau, James B. Grace, Anne Larigauderie12, Diane S. Srivastava13 & Shahid Naeem. Biodiversity loss and its impact on humanity. *Nature* 486, 59–67 (2012). DOI: 10.1038/nature11148.
 28. Santiago Soliveres, Fons van der Plas, Peter Manning, Daniel Prati, Martin M. Gossner, Swen C. Renner, Fabian Alt, Hartmut Arndt, Vanessa Baumgartner, Julia Binkenstein, Klaus Birkhofer, Stefan Blaser, Nico Blüthgen, Steffen Boch, Stefan Böhm, Carmen Börschig, Francois Buscot, Tim Diekötter, Johannes Heinze, Norbert Hölzel, Kirsten Jung, Valentin H. Klaus, Till Kleinebecker, Sandra Klemmer, Jochen Krauss, Markus Lange, E. Kathryn Morris, Jörg Müller, Yvonne Oelmann, Jörg Overmann, Esther Pašalić, Matthias C. Rillig, H. Martin Schaefer, Michael Schloter, Barbara Schmitt, Ingo Schöning, Marion Schrupf, Johannes Sikorski, Stephanie A. Socher, Emily F. Solly, Ilja Sonnemann, Elisabeth Sorkau, Juliane Steckel, Ingolf Steffan-Dewenter, Barbara Stempfhuber, Marco Tschapka, Manfred Türke, Paul C. Venter, Christiane N. Weiner, Wolfgang W. Weisser, Michael Werner, Catrin Westphal, Wolfgang Wilcke, Volkmar Wolters, Tesfaye Wubet, Susanne Wurst, Markus Fischer & Eric Allan. Biodiversity at multiple trophic levels is needed for ecosystem multifunctionality. *Nature* 536(7617):456-459. DOI: [10.1038/nature19092](https://doi.org/10.1038/nature19092)
 29. WorldClim. Global Weather & Climate data. <https://www.worldclim.org/data/index.html>.