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IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

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Abstract: This article systematically analyzes the effects of contemporary climate change on biological diversity. The study examines the mechanisms through which rising global temperatures, altered precipitation regimes, droughts, heatwaves, extreme hydro-meteorological events, ocean warming and acidification affect species, populations and ecosystems. Particular attention is paid to the anthropogenic factor—including fossil-fuel combustion, deforestation, intensive use of land and water resources, urbanization, pollution, and habitat fragmentation—which, in combination with climate change, intensifies pressure on biodiversity. The article synthesizes findings from long-term ecological observations, phenological studies, experimental warming, and trophic manipulation experiments. Changes in flowering periods, bird migration, insect development, and mismatches within food webs are analyzed on the basis of scientific evidence. The vulnerability of mountain, desert, riverine, and Aral Sea region ecosystems in Uzbekistan to climate-related risks is also examined. The findings demonstrate the need to reduce greenhouse-gas emissions, protect and restore natural habitats, develop ecological corridors, manage water resources sustainably, and strengthen long-term biodiversity monitoring in order to conserve biodiversity.

Keywords: climate change, biodiversity, anthropogenic factor, anthropogenic impact, ecosystem, phenology, ecological balance, global warming, drought, biodiversity monitoring.

Changes in the climate system and the decline of biodiversity are among the interconnected global environmental challenges of the twenty-first century. Biodiversity encompasses diversity at the genetic, species, and ecosystem levels and provides the ecological services on which humanity depends, including food, clean water, pollination, soil fertility, carbon sequestration, and natural pest control. Therefore, the loss of biodiversity is not merely a nature-conservation issue but also a matter of economic and social sustainability.

An important characteristic of contemporary climate change is its anthropogenic nature. Changes in energy production, industry, transport, agriculture, and land use increase the concentration of greenhouse gases in the atmosphere. NASA and IPCC data indicate that human activity is the principal cause of the global warming observed in recent decades [1; 2]. In addition to climate factors themselves,

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deforestation, fragmentation of natural areas, overexploitation, pollution, and invasive species also exert pressure on biodiversity [3].

The relevance of the topic lies in the fact that climate change affects biological organisms through several pathways simultaneously: it intensifies physiological stress, shifts species ranges, alters the timing of reproduction and migration, disrupts interactions within food webs, and increases the frequency of extreme events. In particular, in natural landscapes already fragmented by human activity, species find it more difficult to move in response to changing climatic conditions.

The aim of the study is to synthesize, on the basis of scientific sources, the mechanisms through which climate change affects biodiversity, demonstrate the amplifying role of the anthropogenic factor, and substantiate scientific and practical directions for biodiversity conservation.

Research objectives: to identify the mechanisms by which climate change affects biological systems; to analyze changes in species ranges and phenological processes; to assess cascading consequences at the ecosystem level; to reveal the interaction between human activity and climatic factors; to identify pressing risks for Uzbekistan's ecosystems; and to scientifically substantiate conservation and adaptation measures.

The object of the study is biodiversity and ecosystem processes under conditions of climate change. The subject of the study is the effect of changes in temperature, humidity, precipitation, and extreme events on species, populations, phenology, and trophic interactions.

The IPCC Sixth Assessment Report notes that climate change has already caused significant biological changes in terrestrial, freshwater, and marine ecosystems [2]. Many species have shifted their geographic ranges toward higher latitudes or higher-elevation mountain regions. At the same time, not all species are able to move at the same rate, which may disrupt ecological interactions and food webs.

The IPBES global assessment identifies changes in land and sea use, direct exploitation of organisms, climate change, pollution, and invasive alien species as direct drivers of changes in biodiversity [3]. The combined effects of these factors reduce the resilience of biological systems.

A study by Wolkovich and colleagues comparing field observations and warming experiments involving 1,634 plant species demonstrated that plant phenological responses to climate are complex [4]. The authors emphasized that



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changes recorded in field observations may differ substantially from the results of simple experimental warming. This finding indicates that assessing natural ecosystems solely on the basis of laboratory experiments is insufficient.

Phenological mismatches have also emerged as a distinct area of scientific research. Earlier leaf-out or accelerated insect development may become decoupled from the timing of bird migration and reproduction. Such mismatches can increase the gap between the period of peak food-resource availability and the period when consumers require those resources [5; 6].

The study is theoretical and analytical in nature and comparatively analyzes international scientific reports, peer-reviewed articles, and findings from long-term ecological observations. The principal methods used were systematic literature review, comparative analysis, ecological synthesis, cause-and-effect analysis, and generalization of scientific findings.

Three criteria were applied in selecting sources: first, whether the source was produced by a scientific organization or published in a reputable scientific journal; second, whether it directly examined the relationship between climate change and biodiversity; and third, whether it was based on observational or experimental evidence. IPCC and IPBES reports were used as the theoretical foundation because they provide synthesized evidence at the global scale.

Phenological studies have particular methodological importance. The dates of events such as plant flowering and leaf emergence, bird migration, and insect development are compared across multi-year time series. In experimental warming studies, biological responses are observed by increasing temperature under natural conditions. In trophic manipulation experiments, a particular predator or prey group in an ecosystem is temporarily restricted, and the responses of other components of the food web are assessed.

The conclusions presented in the article were interpreted according to the principle of avoiding excessive generalization of causality. In other words, the observation of a biological change in a particular area was not automatically attributed solely to climate change; additional factors such as land use, pollution, resource exploitation, and natural climate variability were also taken into account.

4.1. Effects of Increasing Temperature on Biological Organisms

Each species has a specific temperature range within which it maintains optimal physiological functioning. Exceeding the optimal range affects metabolism, water



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balance, photosynthesis, reproductive processes, and immune responses. When heatwaves persist for long periods, individual stress can translate into population-level mortality and reduced reproductive success.

Another consequence of increasing temperature is the shifting of species ranges. Some cold-adapted species may move toward higher latitudes or elevations. However, roads, agricultural fields, and cities created by humans fragment natural landscapes. As a result, the ability of a species whose climatic niche has shifted to reach new suitable areas becomes limited.

4.2. Precipitation, Drought, and Water Scarcity

Changes in precipitation regimes alter the amount of water available to plants. Drought reduces soil moisture and limits photosynthesis and growth. Prolonged water stress in trees can disrupt the functioning of conducting tissues and increase susceptibility to secondary pests and diseases.

In freshwater ecosystems, climate change is manifested through increased water temperature, seasonal changes in flow, and intensified evaporation. Human water abstraction for irrigation can intensify this natural pressure. Therefore, adaptation to climate change and water-use policy need to be considered together in the conservation of aquatic ecosystems.

4.3. Phenological Shifts and Ecological Mismatches

Phenological processes are among the biological indicators of climate change. Rising temperatures may advance plant flowering and leaf emergence. Insects may also accelerate their development cycles; however, the timing of bird migration may not change at the same rate because it depends on day length, food availability, and other cues.

A comprehensive analysis by Wolkovich and colleagues demonstrated differences between natural observations and experimental warming in plant phenology [4]. This result indicates the need for a multifactorial approach in ecological modeling.

Mismatches between birds and insects directly affect food webs. If the period when chicks are being fed does not coincide with the period of maximum insect biomass, feeding efficiency may decline. Long-term studies have shown that the phenological synchrony between some birds and their food resources changes with climate warming [5].



4.4. Cascading Effects at the Ecosystem Level

Climate change affects ecosystems both directly and indirectly. Direct effects act on organismal physiology through changes in temperature or moisture. Indirect effects are manifested through food webs. For example, a warm spring accelerates insect development, but if bird migration does not change correspondingly, birds may miss the peak period of food availability. A subsequent decline in bird abundance may reduce predation pressure on insects, thereby increasing pressure on plants.

A bird-removal experiment conducted in the Hulun Lake region of China in 2021–2023 experimentally demonstrated such trophic cascades. In areas where bird predation pressure was restricted, grasshoppers increased in abundance, while plant diversity and biomass declined. This result demonstrates the need to assess the biological consequences of climate change within the framework of food webs [7].

Table 1. Climate factors and potential consequences for biodiversity

Climate factor	Biological response	Ecosystem consequence
Increased temperature	Physiological stress; range shifts	Changes in population composition
Drought	Reduced growth and reproduction	Degradation of vegetation cover
Changes in precipitation regime	Shifts in water-dependent species	Changes in the composition of aquatic ecosystems
Heatwaves	Risk of mass mortality	Weakening of ecosystem functions
Shift in seasonality	Phenological mismatch	Disruption of food webs

The results show that climate change affects biodiversity not through simple linear mechanisms, but through complex networks of interactions. A change in one species may affect other species and, through them, the ecosystem as a whole. Therefore, biodiversity monitoring should not be limited to counting rare or highly threatened species.

The anthropogenic factor is one of the important variables determining the scale of these processes. For example, when natural habitat remains continuous, a species may move to another area in response to changing climatic conditions. However, if roads, cities, and intensive agricultural areas interrupt ecological corridors, natural migration of the species is restricted. Therefore, adaptation policy for climate change should be integrated with landscape planning.



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Integration between nature conservation and climate policy is also important for biodiversity conservation. Restoring forests and wetlands can simultaneously improve biological habitat and enhance carbon storage. However, any nature-based solution should be implemented with consideration of local biological conditions, water balance, and the risk of invasive species.

In Uzbekistan, the issue of water resources is particularly important. A dry continental climate, drought risk, and anthropogenic water pressure may jointly affect river, lake, and wetland ecosystems. The Aral Sea region demonstrates that when human activities and natural climatic factors interact, long-term changes can occur in ecological systems.

In mountain ecosystems, it is important to systematically monitor the altitudinal distribution of biodiversity. Climate warming may shift some species toward higher zones, but mountain peaks have physical limits. Therefore, ecological corridors, protected areas, and long-term monitoring should be priority directions for mountain ecosystems.

A limitation of the study is that the article is based on the systematization of existing scientific evidence rather than on the results of new field experiments. Because climatic and anthropogenic conditions differ substantially among regions, transferring global conclusions directly to a specific area requires caution. In the future, it would be appropriate to integrate standardized phenological, population, and genetic monitoring data from different natural zones of Uzbekistan.

Scientific and practical recommendations for Uzbekistan: First, the long-term biodiversity monitoring system should be strengthened at the regional level. Data on temperature, precipitation, soil moisture, and water regimes should be integrated with phenological indicators of plants and animals.

Second, ecological connectivity among natural habitats should be maintained. Planning protected areas not as isolated islands but as a system connected by ecological corridors can increase species' ability to adapt to climatic shifts.

Third, the concept of environmental flows should be incorporated into practical water management in aquatic ecosystems. Maintaining the minimum seasonal flow required by biological communities in rivers is important for fish, aquatic plants, and waterbirds.



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Fourth, agroecological approaches that conserve soil moisture, save water, and support biodiversity should be expanded in agriculture. Preserving natural habitats for pollinators can help stabilize certain components of agricultural productivity.

Fifth, education and public awareness concerning the biological consequences of climate change should be strengthened. Reducing the negative impact of human activity requires not only technological measures but also responsible resource-use practices and environmental responsibility.

The analysis demonstrates that climate change has multilevel effects on biodiversity. Rising temperatures, changes in precipitation regimes, drought, and extreme events alter the physiological condition, range, reproduction, and seasonal processes of organisms. However, explaining changes in biodiversity solely in terms of climate is scientifically insufficient. The ways in which humans use land, water, and biological resources can intensify or reduce these effects.

Scientific observations and experiments indicate that phenological mismatches, cascading changes in food webs, and habitat fragmentation are important mechanisms through which climate change affects biodiversity. Therefore, biodiversity conservation strategies should integrate the species, population, and ecosystem levels.

The main priorities for Uzbekistan are to protect aquatic and terrestrial ecosystems, preserve the ecological integrity of mountain and desert regions, support restoration processes in the Aral Sea region through scientific monitoring, develop ecological corridors, and reduce anthropogenic pressure.

The overall scientific conclusion is that combating climate change and conserving biodiversity will produce sustainable results only when they are pursued not as separate objectives but as interconnected directions of a unified environmental policy. Conserving natural ecosystems, reducing greenhouse-gas emissions, and making human activities more environmentally sustainable are essential conditions for preserving biological resources for future generations.

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