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Effect of climate change on biodiversity, Distribution and survival of wildlife.

Dr Shamim Ahmed Banday[1]
[1]Associate Professor.Department of Zoology, SKC GOVERNMENT DEGREE COLLEGE POONCH
Email id : dr.sanb20@gmail.com
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ABSTRACT
Climate change has emerged as one of the most pervasive drivers of global environmental change, exerting profound effects on biodiversity, species distribution, and the long-term survival of wildlife populations. Rising atmospheric and oceanic temperatures, shifting precipitation regimes, rising sea levels, and an increased frequency of extreme climatic events are altering the structure and function of ecosystems across every biome on Earth. These changes manifest through both direct pathways, such as heat stress, physiological impairment, and altered phenology, and indirect pathways, including habitat loss, food-web disruption, the emergence of infectious diseases, and the proliferation of invasive species. As a consequence, numerous taxa are undergoing measurable shifts in their geographic ranges, often moving poleward or to higher elevations in search of suitable climatic conditions, while species with limited dispersal ability or narrow ecological tolerances face heightened extinction risk. This review synthesizes current scientific understanding of the mechanisms through which climate change affects wildlife biodiversity, distribution, and survival, drawing on evidence from terrestrial, freshwater, and marine ecosystems. It further examines adaptive responses exhibited by wildlife, including behavioural plasticity, morphological adaptation, and range shifts, and discusses mitigation and conservation strategies such as protected area expansion, ecological restoration, assisted migration, and climate-resilient management planning. The review concludes that while some species demonstrate a capacity to adapt to changing climatic conditions, the pace of contemporary climate change frequently outstrips the adaptive capacity of many organisms, underscoring the urgent need for coordinated global action, robust monitoring frameworks, and science-based conservation policy to safeguard wildlife biodiversity for future generations.
Keywords: Climate change, Biodiversity, Wildlife distribution, Species survival, Habitat loss, Conservation.....

INTRODUCTION

Biodiversity, encompassing the variability among living organisms at the genetic, species, and ecosystem levels, forms the foundation of ecological stability and human well-being (Diaz et al., 2019). Wildlife populations contribute to nutrient cycling, pollination, seed dispersal, pest regulation, and carbon sequestration, in addition to providing substantial cultural, recreational, and economic value to human societies (Cardinale et al., 2012). Over the past century, however, global biodiversity has undergone unprecedented decline, driven primarily by habitat destruction, overexploitation, pollution, invasive species, and, increasingly, anthropogenic climate change (Dirzo et al., 2014).

Climate change refers to long-term shifts in temperature, precipitation, and associated weather patterns, largely attributable to the accumulation of greenhouse gases released through fossil fuel combustion, deforestation, and industrial activity since the onset of the industrial revolution (IPCC, 2021). Global mean surface temperature has already increased by approximately 1.1°C above pre-industrial levels, and continued emissions are projected to raise this figure further within the coming decades (IPCC, 2021). Such warming is accompanied by rising sea levels, ocean acidification, glacial retreat, and an increase in the frequency and intensity of extreme weather events, including heatwaves, droughts, floods, and wildfires (Walther et al., 2002).

The implications of these changes for wildlife biodiversity are extensive and multifaceted. Species respond to changing climatic conditions through behavioural, physiological, morphological, and phenological adjustments, and, where such adjustments prove insufficient, through shifts in geographic distribution or, ultimately, population decline and extinction (Parmesan and Yohe, 2003; Root et al., 2003). Numerous studies have documented poleward and upward range shifts among terrestrial and marine taxa, altered timing of breeding and migration, and disruption of predator-prey and plant-pollinator interactions as a consequence of ongoing climatic change (Thomas et al., 2004; Visser and Both, 2005). Furthermore, climate change interacts synergistically with other anthropogenic stressors, such as habitat fragmentation and pollution, to amplify extinction risk beyond what any single factor would produce in isolation (Mantyka-Pringle et al., 2012).

This review article examines the effects of climate change on wildlife biodiversity, with particular emphasis on the mechanisms driving changes in species distribution and survival. It further discusses the adaptive capacity of wildlife populations, highlights representative case studies from terrestrial and marine ecosystems, and outlines mitigation and conservation strategies that can help safeguard global biodiversity in the face of accelerating environmental change.

Biodiversity and Its Ecological Importance

Biodiversity underpins the functioning of ecosystems and the delivery of ecosystem services upon which human societies depend, including food production, water purification, climate regulation, and disease control (Cardinale et al., 2012). Diverse ecological communities tend to exhibit greater resilience and stability in the face of environmental perturbation, as functional redundancy among species buffers ecosystems against the loss of any single component (Oliver et al., 2015). The loss of biodiversity, conversely, diminishes ecosystem productivity and resilience, with cascading consequences for both wildlife and human communities (Hooper et al., 2012).

Wildlife biodiversity holds intrinsic, utilitarian, and aesthetic value. Numerous species serve as keystone or umbrella species, whose presence or absence structures entire ecological communities; the decline of apex predators, for instance, can trigger trophic cascades that alter vegetation structure and species composition across an ecosystem (Ripple et al., 2014). Given this foundational role, understanding and mitigating the effects of climate change on wildlife biodiversity is essential not only for the conservation of individual species but for the maintenance of ecosystem integrity at large.

Mechanisms Linking Climate Change to Biodiversity Loss

Climate change affects wildlife biodiversity through a combination of direct and indirect mechanisms. Direct mechanisms include physiological stress arising from elevated temperatures, altered precipitation, and extreme weather events, which act immediately upon individual organisms. Indirect mechanisms operate through changes to habitat structure, food availability, disease dynamics, and species interactions, and often manifest over longer timescales (Bellard et al., 2012). These pathways rarely operate in isolation; rather, they interact in complex, often nonlinear ways that can amplify their combined impact on wildlife populations (Pfenning-Butterworth et al., 2024).

A useful framework for understanding these effects distinguishes between changes in the abiotic environment (temperature, precipitation, sea level, ocean chemistry) and the biotic responses these changes elicit (behavioural, physiological, phenological, and distributional shifts). The following sections examine each of these pathways in turn, before considering their cumulative consequences for species distribution and survival.

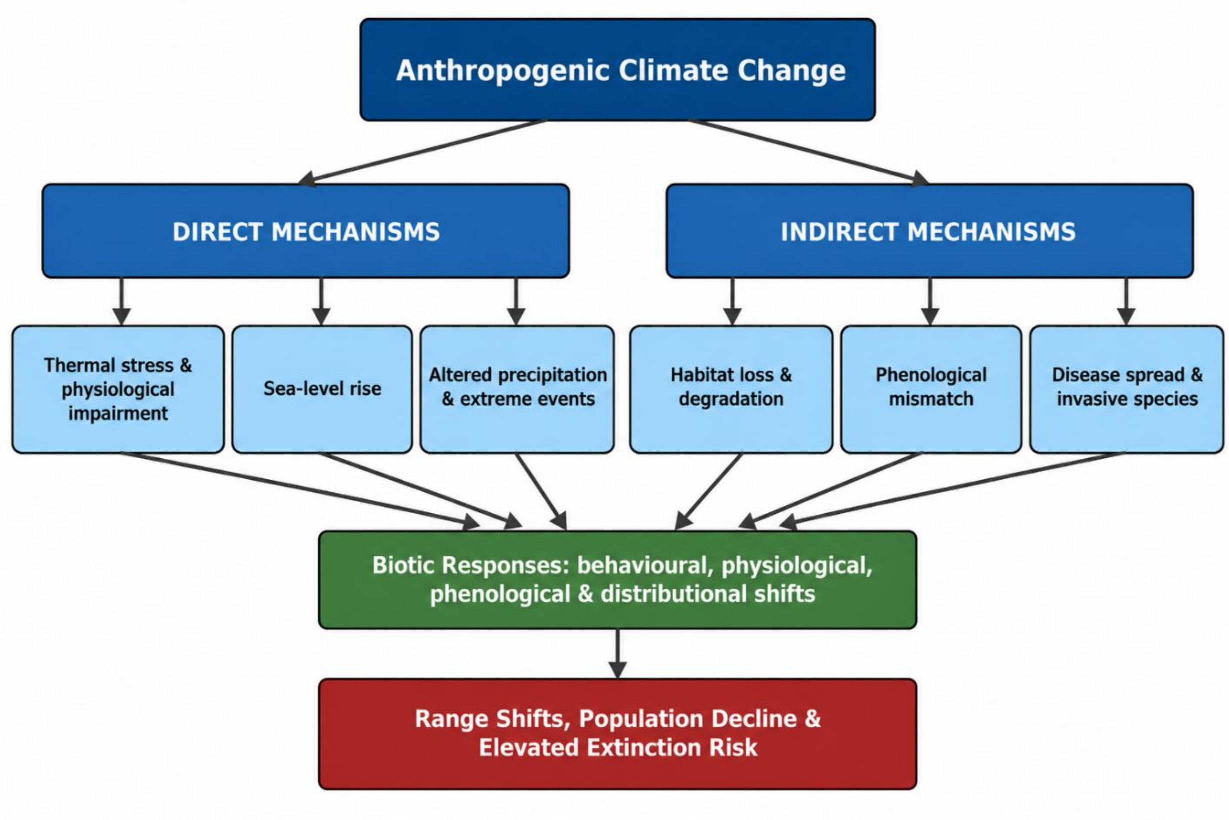

Figure 1: Conceptual Framework Linking Climate Change to Wildlife Biodiversity Loss

The framework in Figure 1 summarises the causal chain examined in the following sections. Anthropogenic climate change acts on wildlife through direct mechanisms, such as thermal stress, sea-level rise, and altered precipitation, and indirect mechanisms, such as habitat loss, phenological mismatch, disease spread, and invasive species. Both pathways converge on a shared set of biotic responses, behavioural, physiological, phenological, and distributional, that ultimately determine range shifts, population decline, and extinction risk.

Table 1: Summary of Direct and Indirect Mechanisms Linking Climate Change to Wildlife Biodiversity Loss

Mechanism Type	Pathway	Representative Example / Effect on Wildlife	Key Reference(s)
Direct	Thermal stress	Impaired thermoregulation, skewed sex ratios in reptiles with temperature-dependent sex determination	Hansen, 2009; Aulsebrook et al., 2020
Direct	Sea-level rise	Loss of coastal nesting habitat for marine turtles and shorebirds; Sundarbans tiger habitat loss	Mukul et al., 2019; Von Holle et al., 2019
Direct	Altered precipitation / extreme events	Reduced carrying capacity for herbivores during drought; nest destruction during floods	Spinoni et al., 2014; Thomey et al., 2011
Indirect	Habitat loss / degradation	Coral bleaching and reef collapse; Arctic sea-ice loss affecting polar bears and ringed seals	Hoegh-Guldberg et al., 2007; Pagano and Williams, 2021
Indirect	Distribution / range shifts	Poleward range shift of 6.1 km per decade across taxa; mountaintop extirpation	Parmesan and Yohe, 2003; Freeman et al., 2018
Indirect	Phenological mismatch	Reduced fledging success when caterpillar peak precedes chick hatching	Visser and Both, 2005; Bonamour, 2021
Indirect	Disease emergence	Chytrid fungus spread linked to shifting temperature and moisture regimes	Pounds et al., 2006; Altizer et al., 2013
Indirect	Invasive species	Broad-tolerance invaders outcompeting native wildlife under novel conditions	Walther et al., 2009

Direct Impacts of Climate Change on Wildlife

Thermal Stress and Physiological Effects

Temperature exerts a pervasive influence on the physiology, behaviour, and reproductive success of wildlife species. Elevated ambient temperatures can impair thermoregulation, reduce foraging efficiency, and compromise reproductive physiology, including spermatogenesis, oogenesis, and embryonic development (Hansen, 2009). Ectothermic species, whose body temperature and metabolic rate are directly regulated by the surrounding environment, are particularly susceptible to thermal stress; amphibians and reptiles, for example, frequently exhibit reduced activity, altered growth rates, and skewed sex ratios under elevated temperature regimes, particularly in species exhibiting temperature-dependent sex determination (Aulsebrook et al., 2020).

Endothermic species are not immune to these pressures. Heat stress in mammals and birds has been associated with reduced feed intake, compromised immune function, and impaired reproductive performance (Hansen, 2009). Behavioural adjustments, such as shifts toward nocturnal activity or increased shade-seeking, represent common short-term coping strategies but may come at the cost of reduced foraging time and increased energetic expenditure (Rabaiotti and Woodroffe, 2019).

Rising Sea Levels

Thermal expansion of ocean water combined with the melting of polar ice sheets and glaciers has driven a sustained rise in global sea level, with current rates estimated at three to four millimetres per year (IPCC, 2019). Rising seas threaten low-lying coastal ecosystems, including mangroves, salt marshes, and beach nesting habitats, through inundation, erosion, and saltwater intrusion into freshwater systems (Mukul et al., 2019). Coastal-nesting species such as marine turtles and shorebirds are especially vulnerable, as rising water levels and increasingly frequent storm surges destroy nests and reduce hatching success (Von Holle et al., 2019). Modelling studies of the Bangladesh Sundarbans, for instance, project substantial loss of suitable habitat for the endangered Bengal tiger under future sea-level rise scenarios (Mukul et al., 2019).

Altered Precipitation Patterns and Extreme Events

Climate change is altering the timing, intensity, and distribution of precipitation across the globe, resulting in more frequent and severe droughts in some regions and increased flooding in others (Spinoni et al., 2014). Such shifts affect the availability of surface water, the productivity of vegetation, and the frequency of wildfires, with cascading consequences for wildlife populations dependent on these resources (Thomey et al., 2011). Prolonged droughts reduce the carrying capacity of ecosystems for large herbivores and can increase competition and mortality around dwindling water sources, while extreme flooding events can destroy nesting sites and displace ground-dwelling and burrowing species alike.

Indirect Impacts of Climate Change on Wildlife

Habitat Loss and Ecosystem Degradation

Climate change contributes to the degradation and outright loss of wildlife habitat through mechanisms such as desertification, coral bleaching, permafrost thaw, and the reduction of polar sea ice (Pagano and Williams, 2021). Coral reefs, which support approximately a quarter of all marine species despite occupying a fraction of the ocean floor, are particularly vulnerable to rising sea surface temperatures, which trigger mass bleaching events and elevate coral mortality (Hoegh-Guldberg et al., 2007). The decline of coral reef structure subsequently reduces habitat complexity and food availability for reef-associated fish communities (Pratchett et al., 2018).

In the Arctic, warming is occurring at more than twice the global average rate, driving substantial declines in sea ice extent and thickness (IPCC, 2019). Species such as polar bears (Ursus maritimus) and ringed seals (Pusa hispida), which rely on sea ice for hunting, resting, and breeding, face diminishing access to these critical habitats, with documented consequences for body condition, reproductive success, and survival (Pagano and Williams, 2021).

Distribution and Range Shifts

One of the most well-documented ecological responses to climate change is the shift in species' geographic ranges toward higher latitudes and elevations, tracking the movement of suitable climatic conditions (Parmesan and Yohe, 2003). A comprehensive meta-analysis by Parmesan and Yohe (2003) found that species range boundaries had shifted poleward by an average of 6.1 kilometres per decade across a broad range of taxa. Similar patterns have been documented among butterflies in Europe and North America, which have expanded their ranges northward and to higher elevations in response to regional warming (Parmesan et al., 1999).

Range shifts, however, are not uniform across taxa, and their extent is strongly influenced by species-specific traits such as dispersal ability, generation time, and habitat specificity (Pacifici et al., 2017). Species with limited mobility, narrow climatic tolerances, or restricted habitat requirements, such as many montane and island endemics, are less able to track shifting climatic conditions and consequently face elevated extinction risk (Sekercioglu et al., 2008). Mountain-top species face a particularly acute form of this challenge, often termed the "escalator to extinction," whereby upward range shifts progressively reduce the area of suitable habitat until no further refuge remains (Freeman et al., 2018).

Marine species exhibit comparable patterns, with many fish stocks shifting poleward in response to ocean warming, altering the composition of fisheries and disrupting established predator-prey relationships (Pinsky et al., 2013). Range shifts of this nature can also bring previously separated species into novel contact, resulting in new competitive interactions, hybridisation, or the introduction of pathogens to naive host populations (Pecl et al., 2017).

Phenological Mismatch

Phenology, the timing of recurring biological events such as flowering, breeding, and migration, is highly sensitive to temperature cues, and climate change has resulted in widespread advances in the timing of spring phenological events across taxa (Walther et al., 2002). While such shifts may appear adaptive in isolation, they can generate mismatches between interacting species when different trophic levels respond to climatic cues at different rates. The classic example of the oak–winter moth–great tit system illustrates this phenomenon: if caterpillar emergence advances more rapidly than the breeding phenology of insectivorous birds, offspring may hatch after the period of peak caterpillar abundance, resulting in reduced food availability and lower fledging success (Visser and Both, 2005; Bonamour, 2021).

Similar mismatches have been documented in marine systems, where shifts in the timing of phytoplankton blooms relative to the arrival of migratory seabirds and marine mammals can reduce foraging success during critical breeding periods (Learmonth et al., 2006).

Emergence and Spread of Diseases

Climate change is altering the distribution and transmission dynamics of wildlife pathogens by modifying the geographic range of vectors, extending transmission seasons, and increasing host susceptibility through nutritional and thermal stress (Ghazali et al., 2018). Warmer temperatures have facilitated the expansion of vector-borne pathogens, such as those transmitted by mosquitoes and ticks, into previously unsuitable regions, exposing naive wildlife populations to novel disease threats (Altizer et al., 2013). Amphibian populations worldwide have been particularly affected by the interaction between climate change and disease, with shifting temperature and moisture regimes implicated in the spread of the chytrid fungus (Batrachochytrium dendrobatidis), a major driver of global amphibian decline (Pounds et al., 2006).

Invasive Species and Altered Species Interactions

Changing climatic conditions can favour the establishment and spread of invasive species, many of which possess broad environmental tolerances and rapid reproductive rates that confer a competitive advantage under novel conditions (Walther et al., 2009). Invasive species often outcompete native wildlife for resources, alter habitat structure, and, in some cases, introduce novel pathogens or predation pressures, compounding the direct effects of climate change on native biodiversity.

Genetic Diversity, Population Decline, and Extinction Risk

Climate change can reduce genetic diversity within wildlife populations through directional selection, population bottlenecks, and reduced gene flow among increasingly fragmented and isolated populations (Bellard et al., 2012). Reduced genetic diversity, in turn, diminishes the adaptive capacity of populations to respond to future environmental change, creating a feedback loop that heightens long-term extinction risk (Hoffmann and Sgro, 2011). Estimates of extinction risk attributable to climate change vary considerably depending on modelling assumptions and future emissions scenarios, but multiple assessments suggest that a substantial proportion of assessed species face an elevated risk of extinction under continued warming, with risk escalating disproportionately at higher levels of warming (Thomas et al., 2004; Urban, 2015).

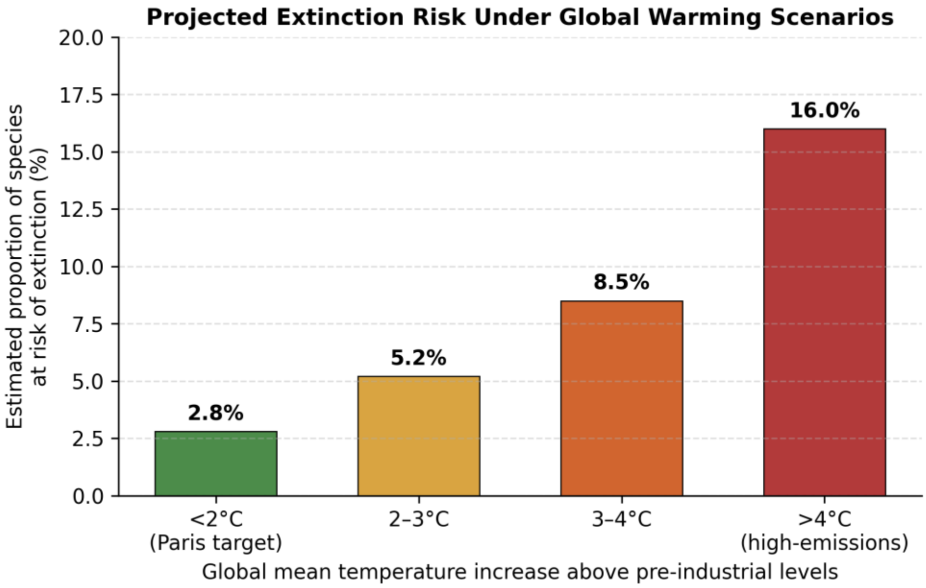

Figure 2: Projected Extinction Risk Under Global Warming Scenarios

Figure 2 illustrates the pattern reported by Urban (2015) in a meta-analysis of extinction risk projections: the proportion of species estimated to be at risk of extinction rises disproportionately as global mean temperature increase escalates, from approximately 2.8% under a Paris-Agreement-consistent trajectory (below 2°C) to roughly 16% under a high-emissions pathway exceeding 4°C. This non-linear escalation underscores why limiting warming is central to biodiversity conservation.

Effects on Wildlife Survival and Population Dynamics

The cumulative effect of the mechanisms described above is a measurable decline in the survival and reproductive success of numerous wildlife populations. Climate-induced changes in food availability, habitat quality, and disease prevalence directly influence key demographic parameters, including birth rates, mortality rates, and age at first reproduction (Mawdsley et al., 2009). Population viability analyses incorporating climate projections indicate that even relatively modest changes in demographic rates can translate into substantial declines in population size over time, particularly for long-lived species with slow reproductive rates (LeDee et al., 2021).

Species respond to these pressures along a spectrum of outcomes. Some populations demonstrate resilience through behavioural plasticity, physiological acclimatisation, or genetic adaptation, allowing them to persist under changing conditions (Hof et al., 2011). Microclimatic refugia, created by local variation in topography, vegetation structure, and canopy cover, can buffer species from the full extent of macroclimatic warming and thereby enhance local persistence (De Frenne et al., 2013). Conversely, populations lacking such buffering, particularly those already reduced in number or restricted to fragmented habitat, face a substantially elevated risk of local extirpation or, in extreme cases, global extinction (Cahill et al., 2013).

Migratory species present a distinct set of challenges, as they depend on suitable climatic and habitat conditions at multiple, often widely separated, points along their migratory route (Moore, 2011). Disruption of climatic cues, food availability, or stopover habitat at any single point in this chain can compromise the entire migratory cycle, with documented consequences including reduced body condition, delayed arrival at breeding grounds, and, in some populations, the cessation of migration altogether in favour of year-round residency (Moore, 2011; Rickbeil et al., 2019).

Representative Case Studies

Polar Bears and Arctic Marine Mammals

Polar bears represent one of the most widely cited examples of climate-driven population decline. As Arctic sea ice extent and duration decline, polar bears face reduced access to seal prey, longer fasting periods, and declining body condition, with corresponding reductions in reproductive success and cub survival documented across several subpopulations (Pagano and Williams, 2021).

Coral Reef Ecosystems

Mass coral bleaching events, driven by anomalously high sea surface temperatures, have become increasingly frequent and severe over the past three decades, resulting in substantial declines in live coral cover across major reef systems, including the Great Barrier Reef (Hoegh-Guldberg et al., 2007). The consequent loss of reef structural complexity reduces habitat availability for reef fish and invertebrate communities, with cascading effects throughout the marine food web (Pratchett et al., 2018).

Migratory Birds and Phenological Mismatch

Long-distance migratory birds are especially susceptible to phenological mismatch, as the cues that trigger migration at wintering grounds may not accurately reflect conditions at distant breeding sites. Studies of European and North American passerines have documented advancing arrival dates at breeding grounds alongside even more rapid advances in the phenology of key food resources, resulting in a growing temporal mismatch between hatching and peak food availability (Visser and Both, 2005).

Adaptive Responses of Wildlife to Climate Change

Wildlife species exhibit a range of adaptive responses to changing climatic conditions, which can broadly be categorised as behavioural, morphological, phenological, and distributional. Behavioural adaptations, such as shifts in activity timing or habitat use, often represent the fastest and most flexible response available to individual organisms (Rabaiotti and Woodroffe, 2019). Morphological adaptations, including reductions in body size under warmer conditions, a pattern consistent with Bergmann's rule, have been documented in species ranging from red deer to marine invertebrates (Post et al., 1997; Le Bris et al., 2017).

Phenological adaptation, involving shifts in the timing of breeding, flowering, or migration, represents a further avenue of response, though as discussed above, such shifts can generate ecological mismatches when not matched by corresponding shifts among interacting species (Bonamour, 2021). Distributional adaptation, through range expansion, contraction, or shift, constitutes a longer-term response operating at the population level rather than the individual level, and is contingent upon the availability of accessible and climatically suitable habitat (Pacifici et al., 2017).

Importantly, the capacity for adaptive response varies substantially among taxa and is influenced by generation time, dispersal ability, genetic diversity, and the degree of habitat connectivity available to facilitate range shifts (Hoffmann and Sgro, 2011). Species with long generation times and limited dispersal capacity are generally less able to keep pace with the current rate of climatic change, raising concern for the long-term persistence of such taxa absent active conservation intervention (Urban, 2015).

Mitigation and Conservation Strategies

Addressing the impacts of climate change on wildlife biodiversity requires an integrated approach combining global greenhouse gas mitigation with targeted, landscape-scale conservation action. The following strategies represent key components of an effective response.

Expansion and Connectivity of Protected Areas

Protected areas remain the cornerstone of global biodiversity conservation, yet current coverage remains insufficient to safeguard the full range of climate-vulnerable species and ecosystems (Jenkins et al., 2015). Expanding the extent and strategic placement of protected areas, while enhancing connectivity through wildlife corridors, can facilitate the range shifts necessary for species to track changing climatic conditions (Pringle, 2017). Climate-informed conservation planning, incorporating projected future distributions of species and habitats rather than relying solely on current distributions, is increasingly recognised as essential for the long-term effectiveness of protected area networks (Wang et al., 2024).

Ecological Restoration and Nature-Based Solutions

Reforestation using native species, restoration of degraded wetlands and peatlands, and rehabilitation of coastal ecosystems such as mangroves and seagrass beds provide dual benefits of enhancing biodiversity resilience and sequestering atmospheric carbon (Edwards et al., 2021). Nature-based solutions of this kind are increasingly incorporated into national climate adaptation and mitigation strategies, reflecting growing recognition of the interdependence between climate stability and ecosystem health (Shin et al., 2022).

Species-Specific and Ex Situ Conservation

For critically endangered species facing imminent extinction risk, targeted interventions such as captive breeding, assisted reproductive technologies, and, in some cases, assisted migration to climatically suitable but currently unoccupied habitat, offer important tools for preventing extinction (Mastromonaco and Songsasen, 2020). Such interventions are resource-intensive and are most effective when integrated within broader landscape-level conservation strategies rather than deployed in isolation.

Climate-Resilient Wildlife Management

Adaptive management frameworks that incorporate ongoing monitoring, scenario planning, and flexible decision-making are essential for responding effectively to the uncertainty inherent in climate projections (LeDee et al., 2021). Provision of supplementary resources, such as artificial water sources during drought periods, and active management of invasive species and disease outbreaks, can help buffer vulnerable populations against acute climatic stressors while longer-term habitat interventions take effect (Chakuya et al., 2021).

Policy, Research, and Community Engagement

Effective conservation in the face of climate change requires supportive policy frameworks, sustained investment in ecological research and monitoring, and the meaningful engagement of local and indigenous communities in conservation planning and implementation (Kideghesho, 2009). International agreements, including the Convention on Biological Diversity and the Paris Agreement, provide important frameworks for coordinated global action, though translating these commitments into effective on-the-ground outcomes remains an ongoing challenge (Sutherland et al., 2025).

Conclusion

Climate change poses a profound and escalating threat to global wildlife biodiversity, acting through a complex web of direct and indirect mechanisms that collectively alter species distribution, survival, and long-term population viability. Rising temperatures, shifting precipitation patterns, rising sea levels, and increasingly frequent extreme weather events are driving measurable changes in the geographic ranges, phenology, and demographic performance of wildlife populations across terrestrial, freshwater, and marine ecosystems. While some species demonstrate notable capacity for behavioural, morphological, and distributional adaptation, the unprecedented pace of contemporary climate change frequently exceeds the adaptive capacity of many taxa, particularly those with limited dispersal ability, narrow ecological tolerances, or already diminished population sizes. The interaction of climate change with other anthropogenic stressors, including habitat loss, overexploitation, and pollution, further compounds these risks, underscoring the necessity of addressing climate change within a broader framework of integrated biodiversity conservation.

Safeguarding global wildlife biodiversity in the face of ongoing climatic change will require sustained reductions in greenhouse gas emissions, expansion and strategic management of protected areas, restoration of degraded ecosystems, and the development of climate-resilient conservation strategies informed by robust scientific research. Continued investment in monitoring and predictive modelling, together with meaningful policy action and community engagement, remains essential to mitigate further biodiversity loss and to preserve the ecological, economic, and cultural value that wildlife biodiversity provides to human society.

Future Perspectives

Future research should prioritise closing critical knowledge gaps regarding species-specific vulnerability to climate change, particularly for understudied taxa and regions where baseline ecological data remain sparse. The development of high-resolution regional climate models, coupled with improved species distribution modelling that incorporates microclimatic variation and biotic interactions, will enhance the accuracy of vulnerability assessments and support more effective, spatially targeted conservation planning. Furthermore, greater emphasis on evaluating the long-term effectiveness of implemented mitigation and conservation measures, through rigorous monitoring and adaptive management, will be essential to ensure that conservation resources are deployed where they can achieve the greatest benefit for global wildlife biodiversity in an era of accelerating environmental change..

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