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Climate Change and Its Impact on Animal Physiology, Distribution, and Evolution: Mechanisms, Adaptations, and Future Perspectives

Kiran Lata Verma*

Assistant Professor, Department of Zoology

MBP Govt PG College Aashiyana Lucknow, Uttar Pradesh, India

**Corresponding author – kiranlata.verma@gmail.com*

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Abstract

Climate change is one of the most important drivers of biodiversity loss and ecosystem transformation in the twenty-first century and has a profound impact on physiology, geographic distribution and evolution of animal species in terrestrial, freshwater and marine settings. Global warming and altered precipitation, increased frequency of extreme weather events, ocean acidification, habitat fragmentation and changing biotic interactions are all altering environmental conditions at an unprecedented rate. Animals respond to these changes through physiological adaptations, behavioral adaptations, phenotypic plasticity and evolution, but the degree of responses varies by species, ecology and region. The physiology of animals changes metabolism, thermoregulation, osmoregulation, endocrine signaling, immune function, oxidative stress and reproductive performance, and all these affect survival and fitness. Climate-induced changes in species distribution, including poleward and elevation range expansion, contractions and migration patterns, are also altering ecology and species interactions. At an evolutionary level, climate change is a powerful selective force that leads to rapid adaptation, phenotypic changes, genetic diversity and in some cases evolutionary rescue or increased extinction risk. Recent progress in genomics, transcriptomics, environmental DNA (eDNA), remote sensing, artificial intelligence and species distribution modeling has drastically improved our understanding of how animals adapt to changing climates and can predict future biodiversity scenarios. This review synthesizes existing knowledge on the physiological, ecological and evolutionary effects of climate change in animals from molecular biology, ecology, evolutionary biology and conservation science. It also highlights new technologies and gaps in knowledge and provides tips for conservation efforts that can help in the future to support the resilience of species in changing climate. With a multi-disciplinary approach and research in biodiversity conservation and ecosystem management in the Anthropocene, this review can further contribute to a deeper understanding of how climate change is changing animal life and will be helpful for future research.

Keywords: Climate change; Animal physiology; Species distribution; Evolution; Phenotypic plasticity; Thermal adaptation; Biodiversity; Global warming; Range shifts; Climate resilience; Environmental DNA (eDNA); Genomics; Conservation biology; Evolutionary adaptation; Anthropocene.

1. Introduction

Climate change is one of the most pressing environmental issues of the 21st century and has profound implications for ecosystem organization and functioning. Fossil fuel combustion, deforestation, industrialization and intensive agricultural activities have been responsible for significantly higher levels of greenhouse gases, mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases have fueled warming, increased precipitation, intensified extreme weather events, increased ocean temperatures and habitat destruction worldwide. According to recent global climate studies, the Earth's average surface temperature has increased by about 1.2–1.3°C since pre-industrial times and it is projected to continue to rise in most future emission scenarios. These changes are happening at a rate not seen in evolution and that many animals are not able to adapt. Animals are particularly vulnerable to climate change because their physiological processes are intimately linked to the environment. Temperature, humidity, water availability, oxygen concentration, and seasonal cycles are important to metabolism, reproduction, growth, immune competence, migration, and behaviour. Even relatively small changes in these environmental parameters can throw out homeostasis, disrupt reproductive success, increase susceptibility to disease and alter the interaction among them. Ectothermic animals, including insects, amphibians, reptiles, and many fish, are particularly sensitive because body temperature is largely dependent on the environment around them. However, endothermic animals such as mammals and birds are also much more affected by heat stress, food availability problems, habitat loss, and disease. Climate change is affecting biodiversity in biological and evolutionary systems. At the physiological level, increased temperatures and environmental stressors lead to changes in metabolism, endocrine function, oxidative balance, immune response, respiratory function, and reproductive function. Most species show physiological plasticity to temporarily adapt to changing environmental conditions, but the magnitude and duration of that adaptation is very limited. When the environment increases beyond physiological tolerance, populations become less fit and suffer from population decline and even extinction. Climate change is changing species distributions worldwide. As temperature increases, many terrestrial and marine organisms have shifted their geographic locations to higher latitudes. These changes are changing the composition of communities, trophic interactions, predator–prey relationships, pollination networks and ecosystem functioning. In many cases they are unable to move quickly enough due to habitat fragmentation, geographic barriers or lacking dispersal ability to reach those areas in a localized way so that they end up losing biodiversity and genetic diversity. Marine ecosystems are also under extreme conditions of rapid migration of species due to ocean warming, deoxygenation and acidification that are affecting fisheries and coral reef biodiversity and coastal ecosystem services. Climate change is a huge evolutionary force. Natural selection pressures on populations are strong enough to put strong natural selection on individuals to breed, and the more individuals with traits which can be adapted to survive and reproduce more in the new climatic conditions of climate change. Adaptive responses are genetic adaptation, phenotypic plasticity, epigenetic adaptation, evolutionary adaptation, epigenetic change and evolutionary rescue. Yet evolutionary response is usually over many generations and may not be able to keep pace with the current climate change rate of change today, especially for the long-lived animals that are still living and have low reproductive rates when the current climate change environment is such that evolution is not a single-celled life cycle and adaptability is no longer a matter of a single generation or more. Thus we are still trying to find the balance between physiological acclimation/accommodation, ecological response and evolutionary adaptation and adaptation in human and animal adaptation and how the balance of physiological adaptation, and the balance of the two are the focus of climate change. Increasing technological innovations have dramatically changed the way we study animals are responding to climate change, and we have been able to assess how they respond to climate change more and more to modern-day climate change. High-throughput sequencing technologies, comparative genomics, transcriptomics, proteomics, metabolomics, eDNA, remote sensing, satellite telemetry, geographic information systems (GIS) and artificial intelligence-based predictive models enable researchers to investigate the biological responses of climate change to the environment from genes to ecosystems. These multi-disciplinary approaches facilitate the identification of molecular biomarkers of stress, the prediction of future species distribution, assessment of adaptive potential and the development of evidence-based conservation strategies. Despite the progress, there is still a lot of knowledge gap. Most studies have been directed at single species or only physiological responses while very few have considered physiological, ecological, molecular and evolutionary responses in a vast diversity of taxa and ecosystems. Moreover, the relationship between climate change and other anthropogenic stressors such as habitat loss, pollution, invasive species and emerging infectious diseases have not yet been fully addressed. The problem arises when the environment is changing from one place to another and not just one place and the environment is changing (which is a very complex process in itself). To solve these phenomena, we need to work in our field of experimental biology, ecology, evolutionary science, computational modeling and conservation planning. This review is a synthesis of previous knowledge on the impacts of climate change on the physiology, geographic distribution and evolution of animals in a world with more than one billion people. It integrates molecular biology, physiology, ecology, evolutionary biology, genomics and conservation science to understand how animals respond in response to changing environments. The review also takes stock of recent technology developments, the research gaps and future trends for climate-resilient biodiversity conservation. This article bridges the gap and provides a holistic view of how climate change is altering animal life in the Anthropocene and how to develop good conservation and management strategies for the protection of biodiversity.

2. Drivers of Climate Change Affecting Animals

Climate change is caused by human and natural factors that are altering the Earth's energy balance and the environment. Natural variations in climate have occurred from the beginning of time, but we can confidently say that climate change is accelerating in recent years due to human activity, especially due to the production of greenhouse gases (GHGs), land-use change, and industrial development. Such factors affect different environmental variables at once, and as a result, stressors that affect animal physiology, behavior, distribution, and evolution are very different. Our understanding of the causes of climate change is necessary in order to understand the mechanisms by which environmental change affects the populations and ecosystems of animals.

2.1 Rising Global Temperature

Global warming is the most widespread impact of contemporary climate change on animals and therefore the most important driver of biological processes. Increasing levels of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases are added to the greenhouse effect and provide heat trapped in the atmosphere of Earth. Global mean surface temperatures have increased significantly since the Industrial Revolution and have risen at an accelerating rate in the past five decades. The increased temperatures are directly associated with metabolic rate, enzyme activity, oxygen use, and cellular metabolism. Ectothermic animals such as insects, reptiles, amphibians, and most fishes are particularly susceptible to elevated temperatures because their body temperature is largely determined by the environment. Higher thermal tolerance limits may hinder growth, reduce reproductive success, increase oxidative stress, and increase mortality. Even endothermic species experience heat stress, dehydration, reduced foraging efficiency, and altered reproductive behavior as the temperature increases. Temperature also impacts the interactions of species in terms of predator-prey dynamics, competition, disease transmission, and so on. So warming affects biodiversity not only physically but also in terms of the organization of ecological systems.

2.2 Altered Precipitation Patterns

Climate change has profoundly changed global precipitation patterns, leading to an extreme range of rainfall frequency, intensity and seasonal distribution. Some regions are experiencing very long droughts and others are experiencing excessive rainfall and flooding. These changes in water quality affect the availability of fresh water, habitat quality and ecosystem productivity. Less rainfall reduces water resources for thermoregulation, osmoregulation and reproduction. Amphibians are particularly susceptible as their permeable skin and breeding cycles depend on adequate moisture. On the other hand, excessive rainfall can destroy nests, dislodge populations, promote pathogen spread and change the food web dynamics. In addition, changes in precipitation also affect vegetation productivity, and thus herbivores and predators depend on them. Thus, changes in rainfall patterns influence the ecosystem so that there are cascading ecological consequences throughout terrestrial and freshwater ecosystems.

2.3 Increasing Frequency of Extreme Weather Events

The frequency, duration, and intensity of extreme climatic events—including heatwaves, cold spells, hurricanes, cyclones, floods, droughts, and wildfires—have increased considerably in recent decades. Unlike gradual warming, these episodic events often exceed the physiological tolerance limits of animals, resulting in sudden population declines.

Heatwaves are among the most significant threats to wildlife, causing dehydration, hyperthermia, reproductive failure, and mass mortality events. Marine heatwaves have triggered widespread coral bleaching and extensive mortality among marine invertebrates and fishes. Similarly, prolonged droughts reduce water availability, concentrate pathogens, and decrease food resources. Wildfires destroy habitats, fragment populations, and alter ecosystem structure, forcing animals to migrate or face increased mortality. Floods can eliminate nesting sites, disrupt breeding cycles, and facilitate the spread of infectious diseases. These disturbances reduce population resilience and may accelerate local extinctions.

2.4 Ocean Warming

The oceans absorb more than 90% of the excess heat produced by greenhouse gas accumulation, making ocean warming one of the most important impacts of climate change. Rising sea temperatures are negatively influencing marine biodiversity at all levels. Marine ectotherms face more metabolic demands, low dissolved oxygen availability, altered reproductive timing, and poorer larval development. Coral reef ecosystems are particularly sensitive because higher temperatures disrupt the symbiotic link between corals and photosynthetic dinoflagellates, resulting in coral bleaching and habitat degradation. Ocean warming also causes poleward shifts in the distribution of marine fishes, plankton, marine mammals, and seabirds, and so fisheries productivity and ecosystem functioning are negatively impacted. As a consequence of this change in distribution, ecological interactions are changed and competition is generated among species.

2.5 Ocean Acidification

Almost a quarter of human carbon dioxide emissions go through the ocean system where CO_2 reacts with seawater into carbonic acid that reduces ocean pH. Ocean acidification reduces carbonate ion production and thus the formation of calcium carbonate structures in corals, mollusks, echinoderms, and many other animals. Less calcification hurts shells and skeletons, makes them more susceptible to disease, and results in lower reproductive rates. Acidification also affects the behavior of fish by reducing their sense of vision, recognition of predators, navigation, and communication. These physiological and behavioral changes have far-reaching implications for marine food webs and ecosystem stability. The combined effects of ocean warming and acidification often lead to synergistic effects that are larger than the impact of either stressor alone.

2.6 Habitat Loss and Fragmentation

Climate change accelerates habitat degradation in the form of desertification, glacier loss, sea-level rise, coastal erosion, vegetation change and increased wildfire frequency. At the same time, anthropogenic land-use changes (urbanization, agriculture, mining and infrastructure development) erode natural habitats and reduce landscape connectivity. Habitat fragmentation restricts dispersal, reduces gene flow, isolates populations and deprives them of access to food and breeding sites. Particularly vulnerable species with limited dispersal ability or special habitat requirements are those with reduced genetic diversity. The relationship between climate change and habitat fragmentation severely limits the ability of many species to change their distributions in response to changing environmental conditions.

2.7 Melting Glaciers, Polar Ice, and Sea-Level Rise

The rapid melting of glaciers and polar ice sheets is contributing to sea level increase at the same time as decreasing the habitats for polar biodiversity. Arctic and Antarctic species (polar bears, seals, penguins and many seabirds) depend on sea ice for food, reproduction and migration. Sea level rise threatens coastal wetlands, mangrove forests, estuaries and nests for sea turtles and shorebirds. Saltwater intrusion disturbs freshwater ecosystems and reduces habitat for many aquatic species. Loss of cryospheric habitat is one of the greatest visible manifestations of climate-driven ecosystem change and shows the vulnerability of very specialized species.

2.8 Changes in Atmospheric Composition and Air Quality

Climate change affects atmospheric chemistry through increased concentration of greenhouse gases, particulate matter, and ground-level ozone. Elevated ozone levels interfere with respiratory function, damage vegetation, and reduce primary productivity, which then affects herbivorous and omnivorous animals. Air pollution also interacts with climatic stress by raising oxidative stress, inflammation, and respiratory disease susceptibility in wildlife. Pollutants can disrupt reproductive physiology, immune function, and development and therefore intensify the physiological impacts of warming. These interrelated stressors often create cumulative biological effects that are more severe than exposure to individual environmental changes.

2.9 Climate-induced changes in biotic interactions

Climate change alters the relationship between species and modifies phenology, geography, and resource availability. The mismatch between flowering plants and pollinators, predators and prey, or hosts and parasites disrupt ecological networks that have been in place for centuries. Warmer temperatures enable the entry of invasive species and disease vectors into previously uninhabited areas. Mosquitoes, ticks, and other arthropod vectors are expanding their ranges and spreading diseases among wildlife, livestock, and humans. New competitive interactions arising from shifting species distributions might put even more stress on native species, especially those with limited ecological niches or limited adaptive capacity.

2.10 Interacting climate stressors

Animals rarely experience one environmental stressor at a time. Rather, many different climatic drivers, such as warming, drought, acidification, hypoxia, habitat fragmentation, pollution, and disease, interplay simultaneously to influence physiological and ecological responses. These interactions may be additive, synergistic, or antagonistic, which can be difficult to predict as biological responses are not well regulated for them. Higher temperatures lead to increased metabolic demand and lower dissolved oxygen concentrations in aquatic environments, which in turn increases physiological stress levels in fishes. Similarly, habitat fragmentation might prevent creatures in the region from moving to more suitable areas, amplifying the effects of warming. These effects can be collectively studied through a multitude of interdisciplinary research frameworks including physiology, ecology, genomics, remote sensing, and predictive modeling. Climate change is connected to a wide range of environmental stressors and therefore changes the biology of animals on a molecular, physiological, and ecological level. Rising temperatures, altered precipitation patterns, ocean warming, acidification, habitat degradation, sea level rise, extreme weather events, and changes in species interactions create unprecedented selective pressures on wildlife. Recognizing these drivers will help us understand the physiological mechanisms, distributional changes, and evolutionary responses discussed in the next sections of the review.

3. Physiological, Behavioral, and Molecular Responses of Animals to Climate Change

Climate change impacts animal biology on many levels of biology from molecular and cellular processes to whole organism physiology and population dynamics. Environmental stressors such as increased temperatures, altered precipitation patterns, ocean acidification, hypoxia, habitat degradation, and increased frequency of extreme weather events pose a challenge for animals to maintain homeostasis, and animals respond differently to these changing conditions by modifying their behavior and molecular processes. With increasing temperature, we see a number of physiological, behavioral, and molecular adaptations that can help species survive. However, if environmental conditions do not allow for adaptation or acclimatization, these responses are insufficient, and the species are losing fitness and reproductive rates, and species interactions with other species from climate change will be compromised, increasing the probability of extinction. These responses are considered in order to predict how well-adapted organisms will be to survive when the environment changes, and the ability to adapt to climate change may be critical for such changes.

3.1 Thermal Stress and Thermoregulatory Responses

Thermal stress and thermoregulatory responses. Temperature is one of the most important environmental factors affecting animal physiology. Climate-induced warming affects biochemical reactions, enzyme activity, membrane stability, and cellular metabolism. Many ectothermic animals, such as insects, amphibians, reptiles, and fish, are dependent on temperature to regulate body functions, making them particularly sensitive to climate change. Even a small increase in environmental temperature can cause a rise in metabolic demands, lower aerobic performance, reduced locomotion, and impaired reproductive processes.

To cope with thermal stress, animals use different thermoregulatory strategies. Behavioral thermoregulation includes seeking shade, burrowing, basking, altering activity periods, or migrating to cooler habitats. Physiologically, many organisms increase peripheral blood flow, evaporative cooling, or respiratory heat loss to maintain internal temperature. Birds and mammals rely on panting, sweating, or gular fluttering, while reptiles and amphibians primarily depend on behavioral adjustments.

At the cellular level, thermal stress destabilizes proteins and membranes, triggering the synthesis of heat shock proteins (HSPs), particularly HSP70 and HSP90. These molecular chaperones stabilize unfolded protein structures, prevent aggregation, and facilitate protein refolding, thereby enhancing cellular tolerance to elevated temperatures. However, chronic heat exposure can overwhelm protective mechanisms, resulting in protein denaturation, mitochondrial dysfunction, oxidative damage, and apoptosis.

3.2 Metabolic and Energetic Responses

Metabolic and energetic responses. Climate change alters energy acquisition, allocation, and expenditure in animals. Elevated temperatures generally increase metabolic rates, consistent with the temperature dependence of biochemical reactions. While higher metabolic activity may enhance growth under favorable conditions, it also increases energy expenditures for maintenance and thermoregulation, leaving fewer resources available for reproduction, immune protection, and development.

Aquatic organisms face additional challenges because warmer water contains lower concentrations of dissolved oxygen. Increased oxygen demand coupled with reduced oxygen availability limits aerobic metabolism, decreases swimming performance, and reduces tolerance to environmental stress. Many fish species exhibit reduced growth rates, impaired reproductive success, and altered feeding behavior under these conditions.

Climate-induced changes in food availability further exacerbate energetic constraints. Droughts reduce primary productivity in terrestrial ecosystems, whereas ocean warming alters plankton communities that support marine food webs. Animals frequently compensate by modifying diet composition, increasing foraging effort, or reducing activity levels, although these strategies may expose them to greater predation risk or energetic costs.

Long-term energetic imbalances ultimately reduce body condition, survival probability, and population growth, particularly in species with high metabolic demands or specialized diets.

3.3 Endocrine and Neuroendocrine Regulation

The endocrine system orchestrates physiological responses to environmental stress by maintaining complex hormonal signaling systems. Climate-related stress affects the hypothalamic-pituitary-adrenal (HPA) axis in mammals and the hypothalamic-pituitary-interrenal (HPI) axis in fishes and amphibians, leading to increased secretion of glucocorticoids (corticosterone, cortisol). Stress-induced glucocorticoid responses release energy reserves, boost cardiovascular performance, and speed up survival. But chronic stress hormone release has adverse effects on immune systems and slows growth, results in impaired reproductive function, and accelerates physiological aging. Climate change also affects thyroid hormones that are responsible for metabolism and development, particularly during metamorphosis in amphibians and seasonal physiological changes in birds and mammals. Melatonin secretion may be altered by changing photoperiod-temperature relationships, which have an effect on circadian systems and seasonal behavior like migration, breeding, and hibernation. Reproductive hormones are also sensitive to environmental stress. Higher temperatures cause testosterone production in many vertebrates to drop, ovarian development and gamete quality to drop, and reproductive timing to change. Endocrine disturbances in animals adversely affect fertility, and reproductive success is a big part of the reason for a very low reproductive success rate in many species.

3.4 Immune function and oxidative stress

Climate change has a direct impact on immune responsiveness. Higher temperatures and nutritional stress suppress the innate and adaptive immune response, and thus increase susceptibility to bacterial, viral, fungal, and parasitic infections. In addition, warmer climates facilitate the spread of pathogens and disease vectors to new areas, increasing disease transmission among wildlife. One of the main mechanisms of climate change-induced physiological damage is oxidative stress. Higher temperatures lead to increased mitochondrial respiration and ROS production. Excessive ROS damage lipids, proteins, nucleic acids, and cellular structures and function. Animals have antioxidant defense systems in superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and reduced glutathione (GSH) that can neutralize reactive oxygen species. However, if the environment is put to the test with stress in the long term, the damage to the environment can overwhelm these protective mechanisms, and the cells eventually become stressed, leading to chronic inflammation, cellular senescence, impaired body functions, and death (a result of chronic inflammation and aging). Oxidative stress biomarkers have become an important indicator of climate-induced physiological stress and are now incorporated into ecological monitoring programs.

3.5 Reproductive and Developmental Responses

And reproductive success is one of the processes most vulnerable to climate change. The higher the temperature, the more reproductive endocrinology, gametogenesis, fertilization, embryonic development, parental care and survival of offspring are affected in many animal species. Many reptiles have temperature-dependent sex determination in which incubation temperature affects the sex of the juveniles. Rising temperatures have led to highly skewed sex ratios in several turtle and crocodilian species and threaten long-term survival of populations. And similar developmental effects are also observed in fishes, amphibians and many invertebrates, where thermal stress decreases egg viability and larval survival and developmental stability. Climate change has also affected reproductive phenology. Early springs and warmer winters affect breeding seasons; emergence timing and food availability are not comparable. Migratory birds may not arrive at breeding sites until the insects are already abundant and chicks are less likely to survive. Marine organisms are also impacted by ocean warming and acidification, which are negatively impacting gamete function, larval calcification, settlement and development of young. Combined, these effects reduce the recruitment rate and increase the chance of extinction for vulnerable species.

3.6 Behavioral Adaptations

Behavioral plasticity is one of the most rapid responses of animals to changing conditions and the fastest way that behavior changes. As with genetic adaptation, behavioral changes can be made during our lifetime as well, and are often the first line of defense against climatic stress. Animals are known to shift their activity schedule in response to changing climate conditions where they are not only more active at night but they are less active during heat waves or when the temperature is low. The range shifts to higher latitudes or higher elevations are also widespread behavioral responses. Birds, mammals, insects, fish and marine invertebrates have expanded into previously cooler regions in more and more places with growing global temperatures. Behavioral flexibility also includes changes in habitat selection, diet breadth, predator avoidance and social interactions. Yet adaptive behavior is often limited when a habitat is not available, dispersal is limited or a species is more specialized. Thus behavioral changes alone may not be able to keep up with fast environmental change.

3.7 Cellular and Molecular Mechanisms of Climate Adaptation

Scientists have made great strides in molecular biology to better understand how animals respond to climate-induced environmental stress. Changes in gene expression are one of the earliest cellular responses to thermal and physiological stress. Transcriptomic analyses reveal differential regulation of genes associated with metabolism, apoptosis, DNA repair, protein folding, antioxidant defense and immune function during climate stress. DNA methylation, histone modification, and non-coding RNAs are also epigenetic factors that contribute to phenotypic plasticity, since they modify gene expression without changing the DNA sequence. These reversible changes lead to rapid acclimation to environmental changes, and could contribute to transgenerational inheritance of adaptive traits. Genomic studies have identified signatures of natural selection in populations exposed to long-term climatic stress, including genes implicated in heat tolerance, osmoregulation, metabolism and immune defense. Proteomic and metabolomic analyses have also found changes in enzyme activity, stress proteins, lipid metabolism and energy pathways associated with adaptation to environmental stress. The integration of genomics, transcriptomics, proteomics, metabolomics and environmental DNA (eDNA) technologies in the field of organisms' responses to climate stress has made life more comprehensible and more complex. It also allows us to predict vulnerability and biomarkers of climate resilience, and with the aid of artificial intelligence, remote sensing and ecological modeling, these approaches are now possible to predict climate resilience in a novel way.

Climate change engenders a vast network of physiological, behavioral and molecular responses that determine the ability of animals to survive in rapidly changing conditions. Thermoregulation, metabolism, endocrine function, immune defense, reproduction and behavior are all key mechanisms of short-term resilience, while molecular and epigenetic responses promote acclimation and adaptive potential. But long-term exposure to a multitude of climatic stressors is often more than physiological adaptations can handle, leading to poor fitness, changes in population dynamics, and higher extinction risk. Understanding these interrelated responses is the foundation for understanding the larger-scale changes in species distributions, biodiversity patterns and evolutionary processes in the next section.

Table 1. Major Climate Change Drivers and Their Physiological Effects on Animals

Climate Change Driver	Primary Environmental Change	Major Physiological Effects	Representative Animal Groups	Potential Ecological Consequences
Rising global temperature	Increased ambient and water temperatures	Heat stress, increased metabolic rate, protein denaturation, oxidative stress,	Mammals, birds, reptiles, amphibians, fishes, insects	Population decline, altered phenology, range shifts

		dehydration, reduced fertility		
Altered precipitation patterns	Droughts, floods, irregular rainfall	Osmoregulatory imbalance, dehydration, reduced reproductive success, impaired growth	Amphibians, freshwater fishes, terrestrial mammals	Habitat degradation, reduced breeding success, local extinctions
Heatwaves	Prolonged extreme temperatures	Hyperthermia, cardiovascular stress, endocrine disruption, increased mortality	Birds, mammals, marine organisms	Mass mortality events, ecosystem instability
Ocean warming	Increased sea surface temperature	Elevated metabolic demand, reduced aerobic capacity, impaired development, altered behavior	Marine fishes, corals, mollusks, crustaceans	Coral bleaching, fisheries decline, poleward migration
Ocean acidification	Decreased seawater pH and carbonate availability	Reduced calcification, impaired sensory function, developmental abnormalities, reproductive impairment	Corals, mollusks, echinoderms, plankton	Reef degradation, biodiversity loss
Habitat loss and fragmentation	Deforestation, urbanization, land-use change	Chronic stress, nutritional deficiency, reduced reproductive fitness, limited gene flow	Mammals, birds, reptiles, amphibians	Population isolation, reduced genetic diversity
Sea-level rise	Coastal inundation and salinization	Osmotic stress, habitat displacement, reproductive habitat loss	Shorebirds, sea turtles, estuarine fishes	Nesting habitat loss, altered migration routes

Glacial and polar ice melt	Loss of sea ice and alpine habitats	Increased energetic expenditure, food limitation, thermal stress	Polar bears, penguins, seals, Arctic foxes	Range contraction, increased extinction risk
Hypoxia (oxygen depletion)	Reduced dissolved oxygen in aquatic systems	Decreased aerobic respiration, ATP depletion, reduced swimming performance	Marine and freshwater fishes, aquatic invertebrates	Reduced productivity, species redistribution
Increased wildfire frequency	Habitat destruction and smoke exposure	Respiratory stress, oxidative damage, elevated glucocorticoid levels	Mammals, reptiles, birds	Habitat fragmentation, mortality, displacement
Air pollution and atmospheric contaminants	Elevated ozone, particulate matter, toxic gases	Lung damage, inflammation, oxidative stress, immune suppression	Birds, mammals, insects	Reduced survival, increased disease susceptibility
Expansion of pathogens and parasites	Climate-favored disease transmission	Immune activation, chronic inflammation, endocrine imbalance	Amphibians, mammals, birds, insects	Disease outbreaks, population decline
Changes in food availability	Altered primary productivity and trophic dynamics	Energy imbalance, reduced body condition, impaired reproduction, developmental delays	Herbivores, carnivores, omnivores	Food-web disruption, reduced population growth
Phenological mismatch	Asynchrony between life-cycle events and resource availability	Nutritional stress, delayed development, reduced reproductive output	Migratory birds, pollinators, mammals	Declining recruitment, altered species interactions

Multiple interacting stressors	Combined warming, pollution, drought, hypoxia, habitat fragmentation	Cumulative physiological stress, endocrine disruption, oxidative damage, immune dysfunction	Most terrestrial and aquatic taxa	Accelerated biodiversity loss and ecosystem instability

Abbreviations: ATP, Adenosine Triphosphate.

Table 2. Animal Taxa and Documented Responses to Climate Change

Animal Taxon	Major Climate Stressors	Documented Physiological Responses	Distributional/Ecological Responses	Representative Examples
Mammals	Heatwaves, habitat loss, drought	Heat stress, elevated cortisol, dehydration, reduced fertility, increased metabolic demand	Poleward and elevational range shifts, altered migration, population decline	Polar bears, bats, elephants, Arctic foxes
Birds	Rising temperature, altered rainfall	Increased respiratory water loss, hormonal changes, reduced breeding success	Earlier migration, altered breeding phenology, range expansion or contraction	Penguins, seabirds, migratory passerines
Reptiles	Warming, habitat fragmentation	Thermal stress, altered metabolic rate, impaired reproduction	Upslope migration, habitat contraction	Lizards, crocodiles, snakes
Amphibians	Drought, warming, emerging diseases	Osmoregulatory stress, immune suppression, developmental abnormalities	Declining populations, local extinctions	Frogs, salamanders, toads

Freshwater Fishes	Elevated temperature, hypoxia	Reduced aerobic capacity, oxidative stress, altered osmoregulation	Upstream migration, reduced abundance	Trout, salmon, carp
Marine Fishes	Ocean warming, acidification	Increased metabolic demand, reduced growth, impaired reproduction	Poleward distribution shifts	Tuna, cod, sardines
Corals	Ocean warming, acidification	Coral bleaching, oxidative damage, impaired calcification	Reef degradation and habitat loss	Reef-building corals
Mollusks	Ocean acidification	Reduced shell formation, developmental impairment	Declining populations	Oysters, mussels, clams
Crustaceans	Ocean warming, hypoxia	Altered molting, reduced growth, metabolic stress	Distributional shifts	Crabs, shrimps, lobsters
Insects	Temperature increase, precipitation changes	Accelerated development, altered diapause, heat stress	Expanded geographic ranges, altered pollination	Butterflies, bees, mosquitoes
Pollinators	Heat stress, habitat degradation	Reduced foraging efficiency, impaired reproduction	Phenological mismatch with flowering plants	Honeybees, bumblebees
Marine Mammals	Ocean warming, prey redistribution	Nutritional stress, endocrine disruption	Migration route alteration	Whales, dolphins, seals

Polar Fauna	Ice loss, warming	Increased energetic expenditure, reduced body condition	Habitat contraction	Polar bears, penguins, walruses
Tropical Species	Heatwaves, drought	Thermal stress, dehydration, oxidative stress	Upslope migration and biodiversity decline	Tropical birds, amphibians, insects
Marine Invertebrates	Acidification, warming	Reduced calcification, impaired larval development	Community restructuring	Sea urchins, starfish, sponges

Table 3. Biomarkers Used in Climate Physiology Studies

Biomarker	Biological Function	Response to Climate Stress	Analytical Method	Research Applications
Heat Shock Protein 70 (HSP70)	Protein folding and cellular protection	Upregulated during thermal stress	Western blot, ELISA, qPCR	Heat tolerance assessment
Heat Shock Protein 90 (HSP90)	Molecular chaperone	Elevated under chronic stress	Western blot, qPCR	Thermal adaptation studies
Cortisol	Primary stress hormone	Increased under environmental stress	ELISA, LC–MS/MS	Physiological stress monitoring
Corticosterone	Stress hormone in birds and reptiles	Elevated during heat and drought	ELISA, RIA	Endocrine response studies
Thyroid hormones (T3, T4)	Metabolic regulation	Altered metabolic activity	Immunoassays	Growth and developmental studies
Reactive Oxygen Species (ROS)	Oxidative metabolism	Increased production under warming	Fluorescent assays	Oxidative stress evaluation

Malondialdehyde (MDA)	Lipid peroxidation marker	Elevated during oxidative damage	TBARS assay, HPLC	Membrane damage assessment
Superoxide Dismutase (SOD)	Antioxidant enzyme	Increased during oxidative stress	Spectrophotometric assay	Antioxidant defense evaluation
Catalase (CAT)	Hydrogen peroxide detoxification	Enhanced activity under stress	Spectrophotometric assay	Oxidative stress monitoring
Glutathione Peroxidase (GPx)	Detoxifies lipid peroxides	Increased in response to ROS	Enzyme activity assay	Cellular antioxidant capacity
Reduced Glutathione (GSH)	Cellular redox balance	Decreased under prolonged stress	Colorimetric assay	Redox homeostasis assessment
Lactate Dehydrogenase (LDH)	Anaerobic metabolism	Elevated during hypoxia	Enzyme assay	Tissue stress indicator
ATP Concentration	Cellular energy status	Reduced under prolonged warming	Bioluminescence assay	Energetic performance analysis
Caspase-3	Apoptosis marker	Increased during severe cellular stress	Immunoblotting, ELISA	Programmed cell death studies
DNA Damage (Comet Assay, 8-OHdG)	Genotoxicity indicator	Increased oxidative DNA damage	Comet assay, ELISA	Environmental genotoxicity assessment
Cytokines (IL-1β, IL-6, TNF-α)	Immune regulation	Altered inflammatory response	ELISA, Multiplex assays	Immune function analysis
Immunoglobulins (IgM, IgG)	Adaptive immunity	Reduced under chronic stress	ELISA	Disease resistance studies

Blood Glucose	Energy metabolism	Elevated during acute stress	Biochemical analyzer	Stress physiology
Blood Lactate	Anaerobic metabolism	Increased during hypoxia and exercise	Enzymatic assay	Physiological performance
Gene Expression Profiles	Molecular stress response	Differential expression of stress-responsive genes	RNA-seq, qRT-PCR	Climate adaptation and transcriptomic studies
DNA Methylation	Epigenetic regulation	Environment-induced epigenetic modification	Bisulfite sequencing	Epigenetic adaptation research
Environmental DNA (eDNA)	Species detection and monitoring	Detects biodiversity changes	Metabarcoding, High-throughput sequencing	Climate-driven biodiversity assessment
Metabolomic Profiles	Cellular metabolic pathways	Altered metabolite abundance	LC–MS, GC–MS, NMR	Systems physiology and stress adaptation
Microbiome Composition	Host-associated microbial communities	Climate-induced microbial shifts	16S rRNA sequencing, Metagenomics	Host resilience and health assessment

4. Climate Change, Species Distribution, Evolution, and Emerging Technologies

Climate change is changing global biodiversity in terms of species distributions, ecological interactions and evolution at unprecedented spatial and temporal scales. Physiological and behavioral responses determine the immediate capacity of organisms to cope with environmental stress, but long-term persistence depends on successful dispersal, adaptation and ecological resilience. Rising temperatures, changing precipitation regimes, ocean acidification and habitat fragmentation are altering environmental suitability in terrestrial, freshwater and marine ecosystems, driving species to shift their geographic locations or adapt to new climatic conditions. At the same time, rapid developments in genomics, remote sensing, artificial intelligence (AI) and environmental DNA (eDNA) have revolutionized the study of climate-related biodiversity change and become powerful tools for monitoring ecosystems and predicting future species responses.

4.1 Climate-induced shifts in species distribution

One of the most obvious biological consequences of climate change is that species move across geographical regions. If the environment is not suitable in a given area, many of them migrate to higher latitudes, higher elevations and deeper aquatic areas, where climate conditions are favorable. Such changes have been observed in various species of mammals, birds, reptiles, amphibians, insects, fishes, corals and marine mammals. Latitudinal range expansion is a phenomenon that is noticeable in temperate regions where warm-adapted species can penetrate the region where the climate was too cold. Cold-adapted animals living in alpine, Arctic and Antarctic regions are reduced in range because they have less space for further migration. Mountain ecosystems are the best example of this phenomenon, with many species slowly moving upward with the warming. But mountaintops are eventually at an "elevational dead end" with no higher habitats, and they are all doomed. Marine ecosystems also are experiencing the same distributional change. Ocean warming has forced many commercially important fish species to poleward migrate with sea levels, altering the productivity of fisheries and ecosystem dynamics. Coral reefs are being pushed to subtropical zones, and the community of plankton in marine food webs has evolved from the feeder to the predator. There are not just temperature factors affecting distributional shifts. Changing rainfall patterns, habitat degradation, changes in vegetation and ocean circulation all influence habitat suitability. Thus, species distributions are more and more dynamic and challenge the concept of stable boundaries.

4.2 Community Restructuring, Biodiversity Loss, and Ecological Interactions

If climate change is changing the ecosystem dynamics, species-based redistribution of species has a profound impact on the composition, trophic relationships, and functioning of species. As the species colonize new environments, new ecological interactions are generated while old ones may be weakened or disappear entirely. These kinds of mismatches with the environment are common in the wake of climate change. The flowering of plants, changes in insect production, and timing of breeding seasons will often disrupt the interdependence of species. Flocks of migrating birds, for example, may arrive at breeding grounds after most of the insects have already arrived and the food supply is not available for their babies. There are also such mismatches between pollinators and flowering plants, predators and prey, parasites and hosts.

4.3 Evolutionary Responses and Adaptive Mechanisms

Climate change also causes the spread of invasive species that are widely dispersed and have a wide range of environmental tolerance and rapid reproductive rates. These species can outcompete native organisms, alter nutrient cycling, change habitat structure, and reduce biodiversity in general. At the same time, warmer climates allow mosquitoes and ticks to spread into areas that were once unsuitable and spread pathogens to wildlife, livestock, and humans. As the situation grows and ecosystem biodiversity suffers due to habitat fragmentation, invasive species, species interactions, and environmental stress, many of the ecosystems are losing biodiversity as a whole. Those with limited ecological niches, limited dispersal ability, and specialized habitat requirements are especially vulnerable. A loss of biodiversity means ecosystem harmony is compromised, ecosystem services are reduced, and natural communities are less effective in the face of future environmental disturbances. Climate change is a powerful evolutionary force by imposing strong selection pressure on populations. Individuals with good survival skills under changing environments are more likely to reproduce, and allele frequencies within populations may be adjusted in a natural way by natural selection. But today's climate change is happening faster than the speed at which many species evolve, particularly long-lived species with extended generation times. Plasticity is one of the primary mechanisms that allow organisms to rapidly adapt to climate change. Plasticity allows individuals to change their morphology, physiology, behavior, and life-history without having to change their genes. Although plastic responses are better for short-term survival, plastic responses do not necessarily provide protection when climate stress is strong or extreme. Selection can occur through a combination of genetic variation or new mutations. More genetic diversity can lead to a greater adaptive potential as there are more traits that natural selection can take into account in a population. On the other hand, the most genetically impoverished populations are at higher risk of extinction due to the lack of evolutionary flexibility. Another factor that is important for climate adaptation is epigenetic regulation. DNA methylation, histone modification, and non-coding RNAs change gene expression without changes to DNA sequences, and these are the mechanisms through which organisms can respond to environmental stress. Some epigenetic changes may even be transmitted in later generations; therefore, the acclimation process is transgenerational. In some situations, rapid adaptation may prevent extinction, which is the process of evolutionary rescue in which beneficial genetic changes increase population growth enough to offset environmental degradation. However, evolutionary rescue is not universal and depends on mutation rate, population size, gene flow, and environmental change.

4.4 Emerging Technologies for Understanding Climate Responses

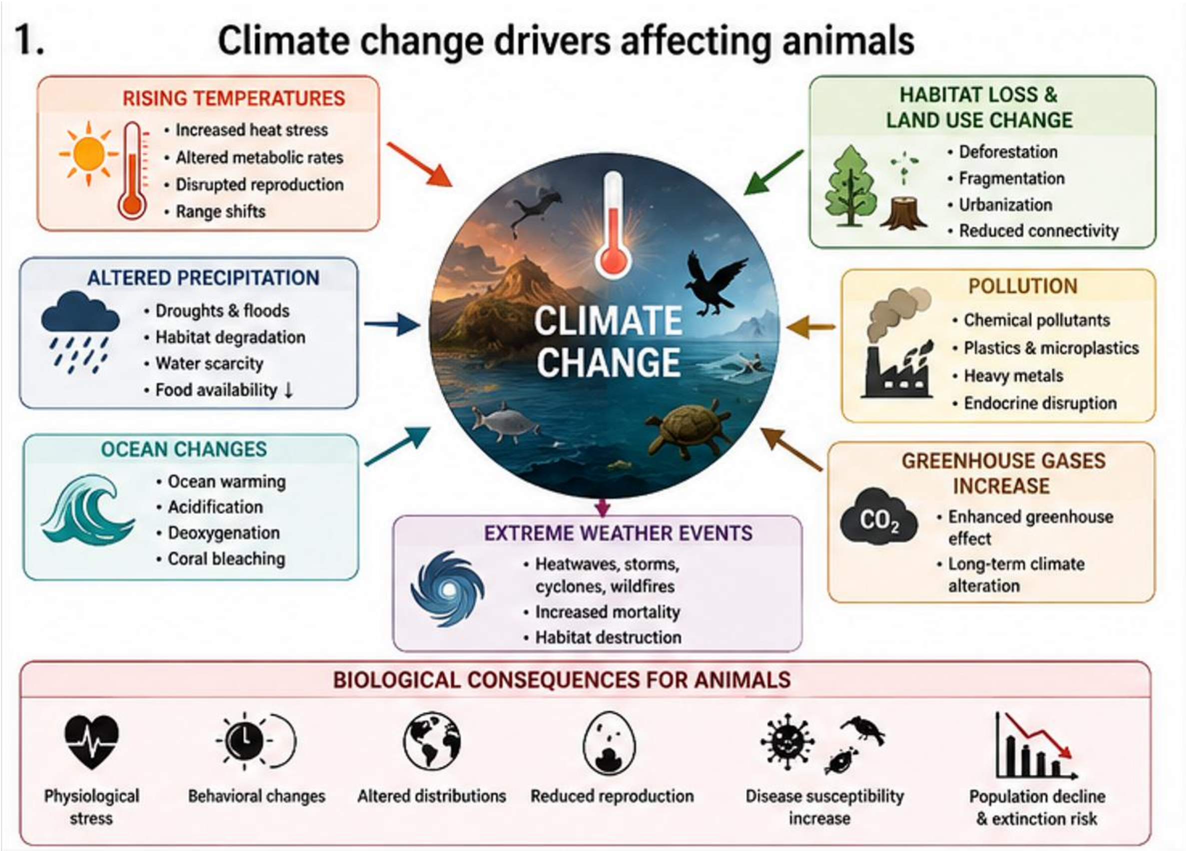
Technology has revolutionized the field of climate biology where scientists are now able to study the responses of animals in molecular, organismal, population and ecosystem scales. High-throughput sequencing technologies have made genomes, transcriptomes, proteomes and metabolomes accessible and molecular systems are now possible to study molecular pathways related to thermal tolerance, immune response, reproduction, and environmental adaptation. Environmental DNA (eDNA) is a powerful and non-invasive method to monitor biodiversity. DNA fragments that are released into water, soil or air by eDNA can then be detected early on to detect rare, endangered species, invasive species or cryptic species that are not detectable by direct observation or the capture of the organism. This is so important for monitoring changes in climate in aquatic life. Remote sensing and Geographic Information Systems (GIS) provide high-resolution information on land cover, vegetation productivity, surface temperature, habitat fragmentation and ecosystem dynamics. Satellite observations help to monitor long-term changes in habitat and enhance the accuracy of ecological models. AI and machine learning have significantly improved the assessment of species distribution across climatic, environmental, ecological and genomic data. These models predict the environment for future habitat development under different greenhouse gas emissions scenarios, identifying vulnerable species and promising climate refugia and conservation areas. Biologging technologies such as GPS telemetry, satellite tracking, accelerometers and biologgers have revolutionized animal movement and behavior in changing climates. These tools provide continuous information on migration routes, habitat use, physiological performance and responses to extreme weather events. Conservation genomics is being used to trace adaptive genetic variations, estimate population connectivity and guide management strategies. With the advent of CRISPR-based functional genomics and gene editing, the potential to explore the genetic basis of climate resilience is increasing, but such methods are still driven by environmental and ethical concerns.

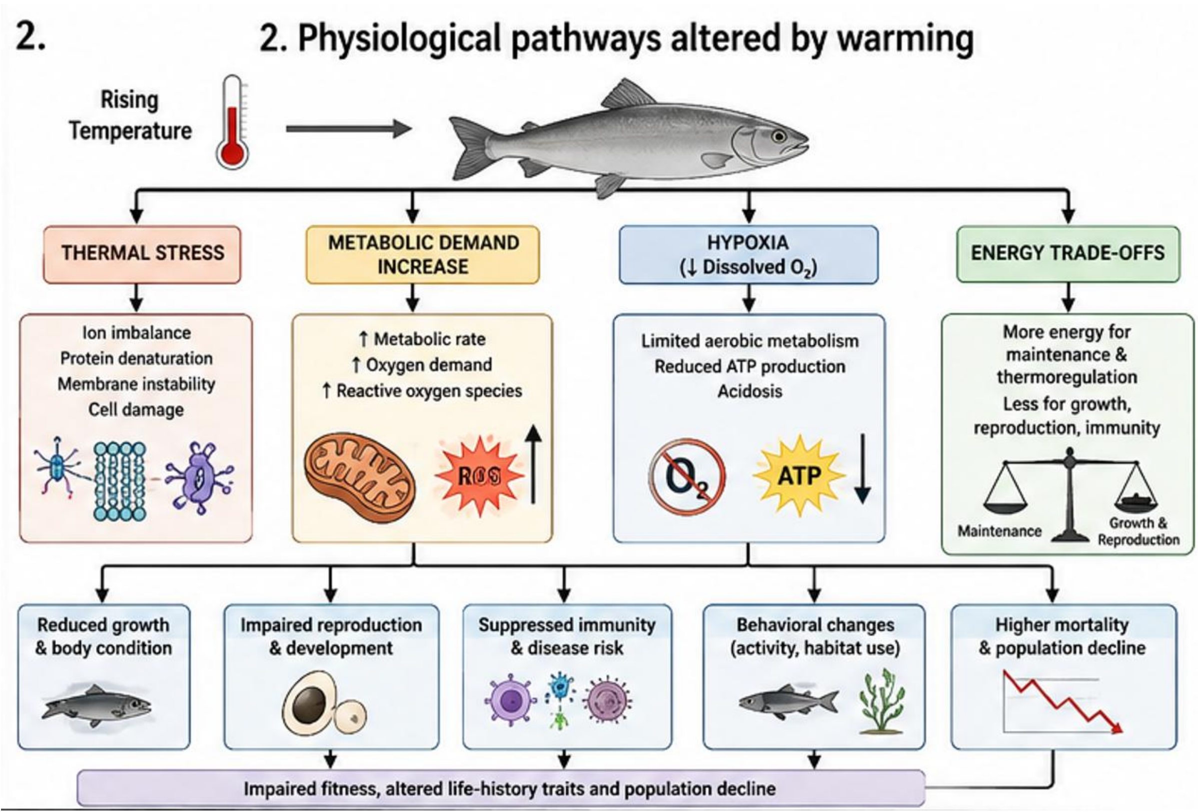
4.5 Integrating Climate Biology with Predictive Conservation

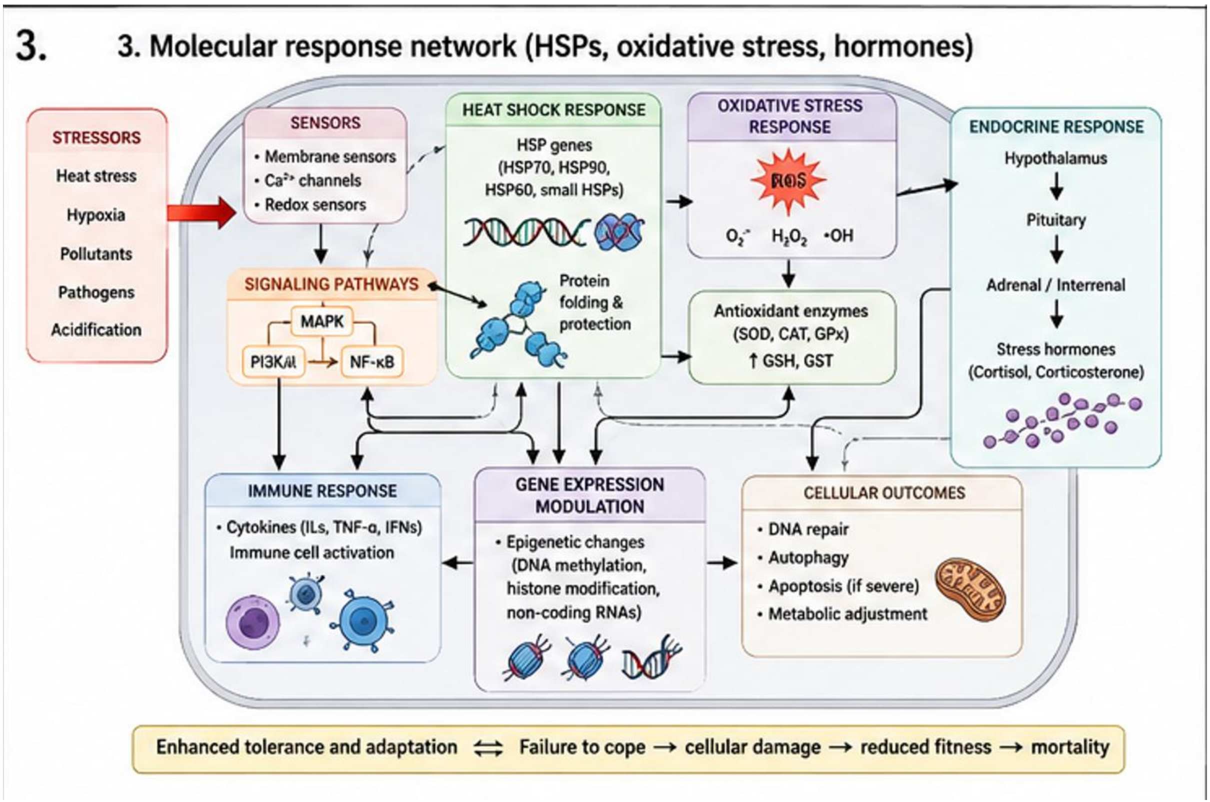
With the continued development of science and technology, the future of biodiversity conservation is based on integrating physiological, ecological, evolutionary, and technological methods. The current climate research is based on cross-disciplinary research and combines laboratory experiments, long-term ecological monitoring, remote sensing, and genomics to predict species in different climate scenarios. Physiological tolerance data is the most applicable ecological models to predict species distribution better than climate factors in general. Similarly, genomic information is needed for ecological models to estimate adaptive capacity and find populations with high evolutionary potential as such. These multidisciplinary approaches are useful for climate-smart conservation planning to identify ecological corridors, climate refugia, assisted migration, and genetically resilient populations. As scientists increasingly realize that successful conservation should consider the interrelation of all the factors: climate change, habitat loss, pollution, invasive species, and emerging infectious diseases, and not only the stressors in isolation. A systems-level understanding of biodiversity responses is therefore critical for adaptation and mitigation strategies. Climate change is ultimately changing the biodiversity distribution, ecology, and evolution of animals in every country. This can be seen in how biodiversity is rapidly changing; range change, loss of biodiversity, community dynamics, and fast development of organisms are just a few examples of the biological effects of climate change. While phenotypic plasticity, genetic adaptation, and evolutionary rescue can make some species more resilient, many are still highly vulnerable due to low adaptive capacity and rapid habitat loss. The combination of genomics, environmental DNA, remote sensing, artificial intelligence, and predictive ecological modeling has greatly advanced our ability to understand and predict climate-induced biological changes. These technological advances are key components of a scientific foundation and evidence-based conservation strategies that are relevant for the survival of biodiversity in the Anthropocene.

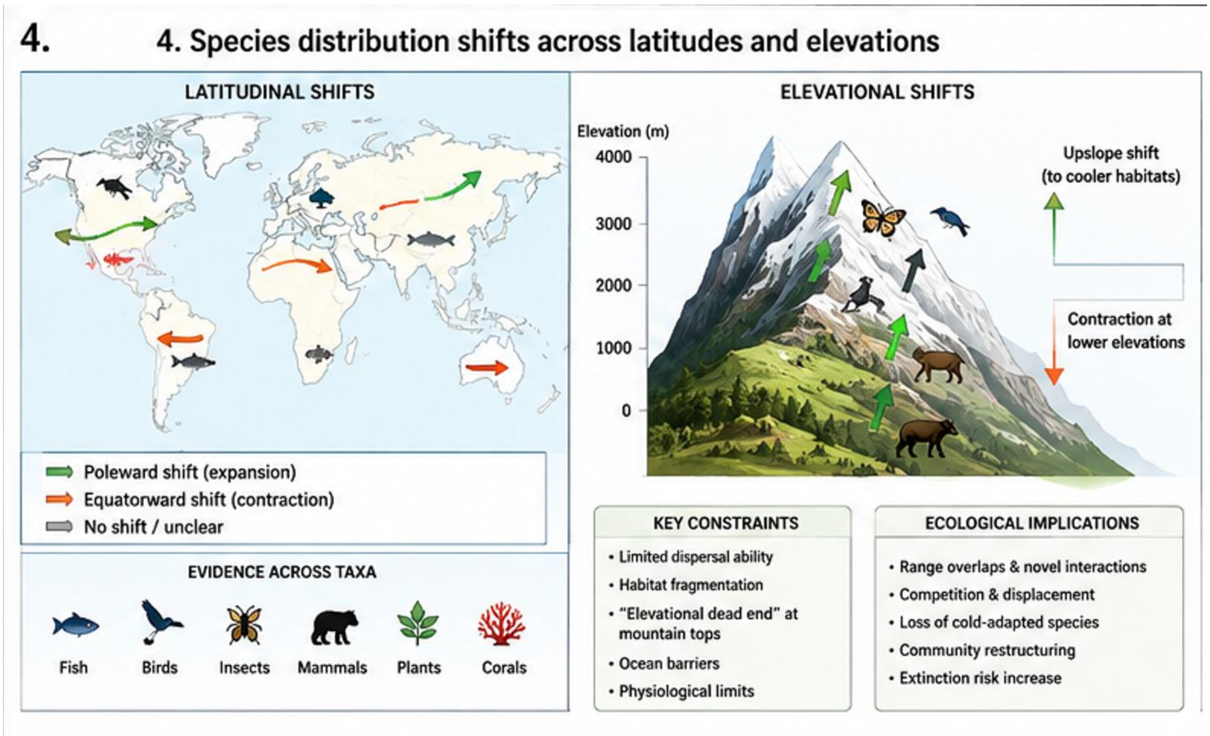
5. Conservation Strategies, Research Gaps, Future Perspectives, and Conclusions

The rapidly changing nature of climate change in animal physiology, distribution, and evolution presents challenges to biodiversity conservation and ecosystem management. While many species are physiologically robust and adaptive, current environmental change rates are so high that populations are not able to adapt biologically and adaptively by acclimation or evolutionary processes alone. The best conservation practice is based on the concept of ecological restoration, conservation genomics, climate modeling, policy-making, technology, and international cooperation. We will discuss the current conservation strategies and what can be done to bridge the gap and the research areas that are presently unexplored, and discuss some of the future research directions and the future of biodiversity conservation in the global climate change.









5.1 Climate-Smart Conservation Strategies

It has been found that nature conservation approaches were the best way to safeguard species in relatively stable settings. But climate change has transformed the world into a dynamic landscape of habitats that can change with time and space. Nowadays, conservation needs to focus on climate-smart conservation (climate-oriented and climate-aware) and how to make future climate change forecasts relevant to biodiversity and conservation planning. One potential approach is to create and expand protected areas where different climatic and environmental conditions and gradients are considered. A protected environment that has multiple habitats is a more natural habitat for species to evolve their distributions. In addition, ecological corridors that connect the fragmented habitats and enable dispersal, migration, and gene flow are important. Habitat restoration is also a crucial part of ecosystem resilience. Reforestation, wetland restoration, mangrove restoration, coral reef restoration, and grassland management are also important to enhance ecosystem functioning and carbon sequestration and reduce climate vulnerability. Restoration should also focus on native species and maintain ecological connectivity to enhance adaptive capabilities. For populations that are extremely vulnerable or geographically limited, assisted migration (managed relocation) has emerged as an alternative conservation strategy. Conservationists may be able to reduce extinction risks due to rapid environmental change by deliberately moving populations to climatically suitable habitats. While this is a promising idea, such assisted migration needs to be carefully managed for ecological risk (e.g., biological invasions or disturbance of recipient ecosystems). Ex situ conservation techniques such as captive breeding programs, zoological institutions, cryopreservation of genetic material, and seed or germplasm banks are also key to protecting endangered species. These are methods that preserve genetic diversity while also laying the groundwork for reintroduction and population recovery in the future.

5.2 Conservation Genomics and Emerging Technologies

Recent advances in molecular biology have revolutionized biodiversity conservation and so have been the assessment of genetic diversity, adaptive potential and population connectivity. Conservation genomics combines whole-genome sequencing, population genetics, transcriptomics and bioinformatics to identify adaptive genetic variation associated with environmental tolerance. Genomic data help to identify populations with alleles that are resistant to heat stress, drought, salinity, hypoxia or disease so that conservation managers can select genetically resilient populations and implement scientifically informed breeding and translocation programs. Landscape genomics can also explore environmental factors with genomic data to understand how climate gradients affect local adaptation. Environmental DNA (eDNA) has become an indispensable tool in biodiversity monitoring. The latter allows for rapid and non-invasive detection of species in water, soil, or sediment samples. eDNA surveys allow for detection of endangered species, early detection of invasive organisms and the community composition in large regions with minimal harm to wildlife. Artificial intelligence (AI), machine learning, and remote sensing have also revolutionized conservation planning. High-resolution satellite images, unmanned aerial vehicles (UAVs), automated acoustic monitoring, camera traps and AI-based image recognition are all tools that help wildlife populations and habitats to be monitored continuously. Machine learning algorithms leverage climatic, ecological, physiological and genomic data to make accurate predictions about species distributions under future climate scenarios. New fields like multi-omics, systems biology and digital ecology provide valuable opportunities to investigate climate responses at a variety of biological scales. Genomics, transcriptomics, proteomics, metabolomics, microbiome analysis and physiological data are integrated into the picture of organismal adaptation and resilience.

5.3 Policy Frameworks and Global Collaboration

Scientific knowledge can't address biodiversity loss without a well-developed policy framework and international collaboration. Climate change is a cross-border issue and needs collective action by governments, scientists, conservation organizations, indigenous peoples, and local communities. International agreements like the Paris Agreement, the Convention on Biological Diversity (CBD), the Kunming-Montreal Global Biodiversity Framework, the Convention on Migratory Species (CMS), and the Ramsar Convention on Wetlands are important mechanisms to integrate climate adaptation with biodiversity conservation. They need to be implemented in ways that are both government-led and well-funded and are subject to monitoring with national commitment. It is also important for governments to include climate adaptation in wildlife management plans, protected area design, environmental impact assessments, and land-use policy. Habitat fragmentation, deforestation, sustainable agriculture, restoring degraded ecosystems, and reducing greenhouse gas emissions are all essential aspects of biodiversity conservation. Community-based conservation has also begun to get recognition. Indigenous peoples and their local communities have some of the best ecological knowledge that complements scientific research and is often very much a part of sustainable resource management. By integrating traditional ecological knowledge with modern conservation science, adaptation strategies can be more effective and social acceptance mechanisms.

5.4 Current Research Gaps

Despite enormous progress in climate biology research, there are still significant knowledge gaps that hinder the prediction of species responses and conservation planning. One of the major limitations is the taxonomic bias of the existing literature. Most studies have focused on economically important, charismatic, or easily accessible species, but invertebrates, tropical organisms, freshwater biodiversity, and deep-sea fauna are much less understood (in the context of biodiversity in general). These groups represent a large part of the biodiversity and require more resources for research. Many studies have only made short-term observations, which do not capture evolutionary processes or take time to adapt to climate change. Long-term monitoring with physiological, demographic, genomic, and environmental data is necessary for the detection of long-term changes in climate. Most experiments assess the individual climatic variables in isolation, but animals are exposed to different stressors at once: warming, drought, pollution, habitat fragmentation, hypoxia, invasive species, and infectious diseases. Future studies should focus on multifactorial studies that are more representative of natural conditions. The links between physiological plasticity and evolutionary adaptation are also still less well understood. More integration of molecular biology, evolutionary genetics, quantitative ecology, and systems biology is needed in order to identify biomarkers of resilience and improve predictions of adaptive capacity. Finally, there is still uncertainty about the ecological impact of new conservation technologies like assisted evolution, genome editing, and synthetic biology. Ethical evaluation, ecological risk assessment, and international governance are necessary before any of this can be fully implemented.

5.5 Future Perspectives

Future research needs to focus on the integration of physiology, ecology, evolutionary biology, genomics, climatology, artificial intelligence and environmental modeling into predictive frameworks. Such integration will help to understand climate-induced biological responses from genes to ecosystems. Early warning systems that detect physiological stress before population declines are established will be a major research goal. Biomarkers from genomics, metabolomics, endocrine physiology, immune function and oxidative stress will help in the planning for conservation. And the development of artificial intelligence will have further effect on biodiversity research through the automatic detection of species, environmental prediction, conservation monitoring and decision-making. Digital twins of ecosystems—virtual models that integrate real-time environmental and biological data—could be helpful in predicting how ecosystems would respond to alternative climate scenarios. More attention needs to be paid to climate refugia, areas of land in which the climate is relatively stable irrespective of global climate change. Conservation of these refugia could significantly improve biodiversity long-term. Increasing international data sharing networks, open-access biodiversity databases, standardized monitoring protocols and collaborative research programs will support scientific progress and conservation. Educating and engaging people, and involving them in climate science and citizen science programs can also enhance biodiversity monitoring and make climate change more accessible and easier to understand. At the same time, conservation is all about how scientific innovation and sustainable environmental policy, ecosystem restoration, greenhouse gas reduction and socio-economic development can work together to make sure there is a healthy ecosystem for wildlife and humans. Climate change and biodiversity loss have to be addressed at the same time to build a resilient ecosystem to support wildlife and human society.

6 Conclusions

Climate change has been one of the most important drivers of biological change in the Anthropocene and has significantly changed animal physiology, species distributions, ecological interactions and evolutionary trajectories in terrestrial, freshwater and marine ecosystems. Rising temperatures, changing precipitation, ocean warming, acidification, habitat loss and increasingly frequent extreme events all contribute to complex environmental pressures that challenge the adaptive capacity of wildlife worldwide. Animals respond in many physiological, behavioral, molecular and evolutionary ways: thermoregulation, metabolic adaptation, endocrine regulation, immune modulation, phenotypic plasticity, genetic adaptation and behavioral flexibility. The responses are adaptable in a variety of ways but few animals can adapt to climate change quickly enough to cope with the high rate of change and extinction. Recent developments in genomics, environmental DNA, remote sensing, artificial intelligence, multi-omics and predictive ecology have significantly improved our understanding of climate-induced biological responses. These tools not only provide insight into the molecular mechanisms of adaptation but can also be used to predict species vulnerability and to design evidence-based conservation policies. For future biodiversity conservation an integrated, interdisciplinary and forward-looking approach which combines climate-smart management, conservation genomics, ecological restoration, sustainable environmental policies, technology and international cooperation will be crucial. Conservation of ecosystem connectivity, genetic diversity, restoration of degraded landscapes, reduction of greenhouse gas emissions and global cooperation will be important to help wildlife populations survive in future climate scenarios. So understanding how climate change influences animal physiology, distribution and evolution is crucial to predicting the future of biodiversity. Scientists and policymakers can make better use of advancements in physiology, ecology, evolutionary biology, molecular science and conservation technology to tackle biodiversity loss and develop resilience. Such cooperation will be crucial to the protection of animals' lives and ecosystems in a world that is warming up.

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