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Review article

Climate change and wildlife biodiversity: Impact and mitigation strategies

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Abstract

Biodiversity plays a fundamental role in natural ecological processes and additionally has utilitarian value in terms of natural resources upon which humans are directly reliant. In the last few decades, biodiversity has been found to decline at an alarming rate and is an increasing concern as the current adverse environmental trends intensify. The leading causes for the loss of biodiversity are excessive exploitation, habitat destruction, urbanization, and, most importantly, anthropogenic climate change. This paper focuses on the various direct and indirect impacts of climate change on wildlife biodiversity, as well as mitigation and conservation strategies to minimize these impacts. Global climate change, a direct or indirect consequence of anthropogenic activities over the last few decades, is a major cause of the decline in wildlife biodiversity. Climate change has numerous impacts on global wildlife biodiversity, including changes in species distribution, emergence and re-emergence of diseases, genetic loss and extinction, habitat loss, loss of soil fertility, nutritional stress, reduction in population size, and spread of invasive species. Assessment of the current environmental trends and future predictions suggests that climate change could have significant impacts on wildlife biodiversity, even if the predicted changes are minimal. Historical patterns show that rapid climate changes have triggered evolutionary shifts in various species, some adapting successfully, while others face population decline or extinction. To combat these challenges, the adoption of effective mitigation and conservation measures is crucial. This article emphasizes the need for continued research to better understand, anticipate, and develop innovative solutions to safeguard global wildlife biodiversity in the face of climate change.

Keywords: Biodiversity, Climate change, Wildlife, Disease incidence, Population, Habitat loss

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Introduction

Biodiversity covers the entirety of the diversity of life at all levels, i.e., within species, between species, as well as the variability of habitats (Kahraman et al., 2012). The most widely accepted definition of biodiversity was formulated at the United Nations Conference on Environment and Development, held on June 05, 1992, in Rio de Janeiro, and is contained within Article 2 of the Convention on Biological Diversity. The convention states that "biological diversity means the variability among living organisms from all sources, including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems".

From the discussion mentioned above, the term "Wildlife Biodiversity" can be defined as all possible variations in wildlife species (flora and fauna), their ecosystems, and the complex ecological processes and relationships among them. Biodiversity plays a fundamental role in the natural ecological process. Additionally, it has utilitarian value in terms of all natural resources, such as food, wood, shelter, organic chemical compounds, and resin upon which humans are directly reliant. It also includes indirect benefits to man in the form of climate regulation, providing habitats for various organisms, maintenance of air and water quality, nutrient cycling, and their associated economic benefits (Alho, 2008). In the last few decades, biodiversity has been declining at an alarming rate and is an increasing concern as the current environmental trends intensify (Franklin, 2010). The leading causes for the loss of biodiversity are excessive exploitation, habitat destruction, urbanization, and, most importantly, anthropogenic climate change.

Global climate change, a direct or indirect consequence of anthropogenic activities over the last few decades, is a significant cause of the decline in wildlife biodiversity. Scientists are of the opinion that climate change could severely affect ecosystems across all latitudes (Dobson et al., 1989) and may aggravate the existing threats to wildlife biodiversity. Climate change has numerous impacts on global wildlife biodiversity, including changes in species distribution, alteration of demographic rates, emergence and re-emergence of diseases, genetic loss and extinction, habitat loss, loss of soil fertility, nutritional stress, reduction in population size, and spread of invasive species (Mawdsley et al., 2009). Alterations in abiotic factors such as environmental temperature, precipitation, wind patterns, and seasonality can result in an alteration of the structure and function of ecosystems, resulting in changes in the distribution patterns of associated flora and fauna (Markham and Malcom, 1996).

Analysis of present environmental patterns and future projections indicates that climate change could significantly affect wildlife biodiversity, even when the anticipated changes appear minor. Historical evidence shows that abrupt climatic shifts have triggered evolutionary adaptations in both plant and animal species (Kilpatrick, 2006). As with all evolutionary processes, certain species may adapt and flourish under new climate conditions, while others may experience population declines or face extinction (Hannah et al., 2005).

This review article focuses on the various direct and indirect impacts of climate change on wildlife biodiversity, as well as mitigation and conservation strategies to minimize these impacts. This literature review seeks to stimulate further research in understanding and predicting the effects of climate change and in developing innovative methods of conserving global wildlife biodiversity.

Importance of conserving wildlife biodiversity

Humankind has been dependent on wildlife biodiversity for centuries. Despite the numerous benefits, there has been a drastic decline in wildlife biodiversity in recent years, mainly owing to unsustainable anthropogenic activity and its associated environmental impacts. The first step to the conservation of global wildlife biodiversity was taken by ecologist Norman Myers, who identified regions rich in biodiversity (Myers et al., 2000). These regions are referred to as 'Biodiversity Hotspots' and are defined as areas that are rich in species, have high endemism, and are facing extensive habitat loss (Reid, 1998). These hotspots are highly susceptible to anthropogenic disturbances, and a large proportion of these habitats are now only present within protected areas (Mittermeier et al., 2004). At present, there are 36 officially recognized wildlife biodiversity hotspots worldwide, which are considered the planet's most biologically diverse yet highly threatened areas. Despite their ecological importance, these hotspots collectively cover only about 2.5% of the Earth's total land surface (Myers et al., 2000).

The threats to species and ecosystems are increasing at an alarming rate and are caused by humans' mismanagement of biological resources. All life forms are unique and warrant a right to be preserved regardless of their value to humans. Apart from ecological services, wildlife biodiversity also provides utilitarian value in the form of biological resources and adds aesthetic value to the natural environment (Rawat and Agarwal, 2015).

The natural environment is a source of entertainment to humans in the form of leisure activities such as bird watching, spot hunting, diving, mushroom picking, or just perceiving nature as it is. A significant amount of tourism is centered around wildlife, which is called ecotourism. In 2006, the U.S. Fish and Wildlife Service's (2007) National Survey of Fishing, Hunting, and Wildlife-Associated Recreation conducted a study that showed that around 87 million Americans were involved in some form of wildlife-associated recreational activity. Some examples of these are dolphin feeding in Australia, butterfly watching in Mexico, bird watching in Thailand or the Galapagos Islands, and monkey viewing at Singapore temples (Manfredo, 2008). The natural or aesthetic value of wildlife biodiversity is a significant reason for conservation and is necessary to enrich human life.

Wildlife biodiversity also provides indirect benefits called ecosystem services, the market value of which is difficult to ascertain. These benefits include the maintenance of air and water quality, soil fertility, rainfall regulation, nutrient cycling, habitat maintenance, and climate regulation (Alho, 2008). The utilitarian and ecological value of wildlife biodiversity is of utmost importance to the survival of the human race, and conservation must be considered a priority.

Various factors affecting wildlife biodiversity

Wildlife biodiversity is influenced by various abiotic environmental factors as well as anthropogenic activities. Soil fertility, availability of water, type of habitat, altitude, climatic conditions, salinity, wave patterns, wind, nutritional requirements, predatory species, and human-induced threats determine the quality, quantity, and type of wildlife biodiversity that flourishes in a particular region. The major factors affecting global wildlife biodiversity are discussed below.

Climate

The climate influences the type of ecosystem present in a particular region. The average temperature, annual rainfall, humidity, and altitude determine the type of vegetation and wildlife that inhabit a particular region. A change in the climate has consequences such as cloudbursts, rising sea levels, elevation of ambient temperature, dry spells, droughts, thawed permafrost, salinization, and increased wildfires (Maqbool et al., 2021). Climate change affects individual species and their habitats, resulting in the alteration of the structure and function of the ecosystems (Diaz et al., 2019).

In the last two decades, an assessment of climate change vulnerability has identified direct and indirect effects on individual species and populations (LeDee et al., 2021). Different species respond to these changes by either persisting, moving to another suitable ecological location, or ceasing to exist altogether (Lyam et al., 2022). Thus, climate plays a vital role in determining a region's wildlife biodiversity.

Nutrition

The growth and reproduction of various species are directly dependent on adequate nutritional intake, and reproductive physiology and sexual behavior are highly sensitive to nutritional intake. Calories alone are not sufficient for the maintenance of health, growth, and other functions. Micronutrients and macronutrients are essential for the proper growth, routine functioning, and reproduction of individuals (Birnie-Gauvin et al., 2017).

In marine ecosystems, seagrass, macroalgae, and phytoplankton are essential sources of nutrition for marine mammals, fish, and invertebrates (Macreadie et al., 2017). The quality and abundance of these nutritional sources are essential determinants of species richness, health, and resilience in the marine ecosystem. Seagrass and kelp ecosystems are declining due to the increased frequency of heat waves and extreme sea temperatures (IPCC, 2014), which will, in turn, affect marine biodiversity.

Anthropogenic activities over the years have resulted in the degradation of the environment, resulting in changes in the quality and quantity of food available to wild animals. This has brought severe implications for the health, reproduction, and survival of many species. Natural and human phenomena have resulted in changes in the composition of vegetation, leading to the destruction of biomass and alteration of the structure and function of these ecosystems (Pickett et al. 1997). The existence of a large number of species is threatened due to these changes in the vegetation (Unanaonwi and Amonum, 2014).

Habitat

In simple terms, a habitat is a region where a species is present. Animals only live in areas where basic resources like food, water, and shelter are available and can adapt to climatic conditions, predatory species, and interspecific competition (Morrison et al., 2012). Degradation, fragmentation, and loss of habitat have led to a decline in the quality of habitat present, with consequent loss of ecosystem services resulting in a decline of wildlife biodiversity (Staudt et al., 2013).

Forest fringe areas are the outer regions of the forest that safeguard the inner core of the forest and face a large amount of extraction pressure from the rural communities living in it (Kumar and Kushwaha, 2020). The communities are highly dependent on these areas for fodder, grazing areas, and fuel wood (Kumar and Kushwaha, 2018). Overexploitation and encroachment of the fringe areas result in increased anthropogenic pressure on the forests, leading to habitat loss. Therefore, habitat conservation strategies are crucial for the conservation of wildlife biodiversity and for promoting a sustainable future.

Human-wildlife conflict

Human-wildlife conflict is the interaction between humans and wildlife, which has a negative impact on humans, wildlife, resources, and/or habitat. Human-wildlife conflict can be attributed to the expansion of human activities into wildlife habitats and the current environmental trends (Treves, 2009), which result in increased competition for limited and dwindling resources. Human-wildlife conflict contributes significantly to the decline in wildlife populations, with species extinction representing its most severe outcome (Dirzo et al., 2014). The decline or loss of top predators, in particular, disrupts ecological balance and leads to a reduction in biodiversity, negatively impacting ecosystem functions and services (Ripple et al., 2014). As human populations continue to grow and the demand for natural resources intensifies, these conflicts become more frequent and severe, posing a serious threat to global wildlife biodiversity.

Importance of studying climate change on wildlife biodiversity

Wildlife biodiversity plays a pivotal role in maintaining ecosystem balance. Various extrinsic factors due to anthropogenic activities, such as climate change, pollution, deforestation, hunting, and poaching, pose a significant threat to global wildlife biodiversity. Understanding such factors and mitigating these human-instigated threats is crucial for the survival of wildlife species (Bellard et al., 2012).

Climate change has a slow but pronounced effect at the individual, population, and species levels in terms of behavior, morphology, phenology, and range shits. On an ecosystem level, it is observed through changes in production, species interactions, and extreme events. The genetic diversity of populations is reduced due to directional selection and migration as a consequence of climate change (Bellard et al., 2012).

Biological diversity and functional ecosystems provide a wide range of ecosystem services that are necessary for human well-being (Diaz et al., 2019). Apart from maintaining the global natural climate, the formation of soil, hydrological cycles, the purification of water, the maintenance of biochemical cycles, the breakdown of pollutants, and waste management are essential ecosystem services provided by biodiversity (Kahraman et al. 2012; Rawat and Agarwal, 2015). Therefore, the impact of climate change on wildlife biodiversity and ecosystems potentially affects the availability and quality of these essential ecosystem services.

The implications of climate change on wildlife biodiversity are a growing field of research (Beaumont et al., 2011; Bellard et al., 2012). The knowledge and future predictions of the response of biodiversity to climate change are important in charting conservation strategies, policy making, and developing novel methods to have a more sustainable life. As climate change progresses, understanding the multifaceted interactions of wildlife biodiversity and environmental stressors is crucial in developing appropriate conservation and mitigation strategies. Failure to do so may result in the implementation of inefficient and potentially harmful conservation strategies.

Impact of climate change on wildlife biodiversity

Climate change is anticipated to affect the population scope and structure of organisms, community construction, and the structure and functioning of ecosystems (Diaz et al., 2019). The change in global climate has led to alterations in the distribution of vertebrates, invertebrates, and plant species in both aquatic and terrestrial environments (Gilg et al., 2017).

Evidence of global climate change has been documented in various ecosystems; however, these changes are negligible at the ground level or microclimate level due to variations in local topography, vegetation structure, canopy configuration, and slope orientation (De Frenne et al., 2013). These microclimates help species adapt to rapidly changing climatic conditions by buffering action. The average temperature at the ground level is substantially lower than the atmospheric temperature due to the reasons stated above. This creates microclimate pockets where species are able to thrive unaffected by changes in the macroclimate. Anthropogenic activities resulting in habitat destruction and fragmentation may lead to fewer microclimate pockets, consequently reducing the possibility of species enduring the effects of climate change (Hof et al., 2011). The causal pathways linking the three global pressures of climate change, biodiversity loss, and infectious diseases have been reviewed by Pfenning-Butterworth et al. (2024). Figure 1 describes both the direct and indirect impacts of climate change on wildlife biodiversity.

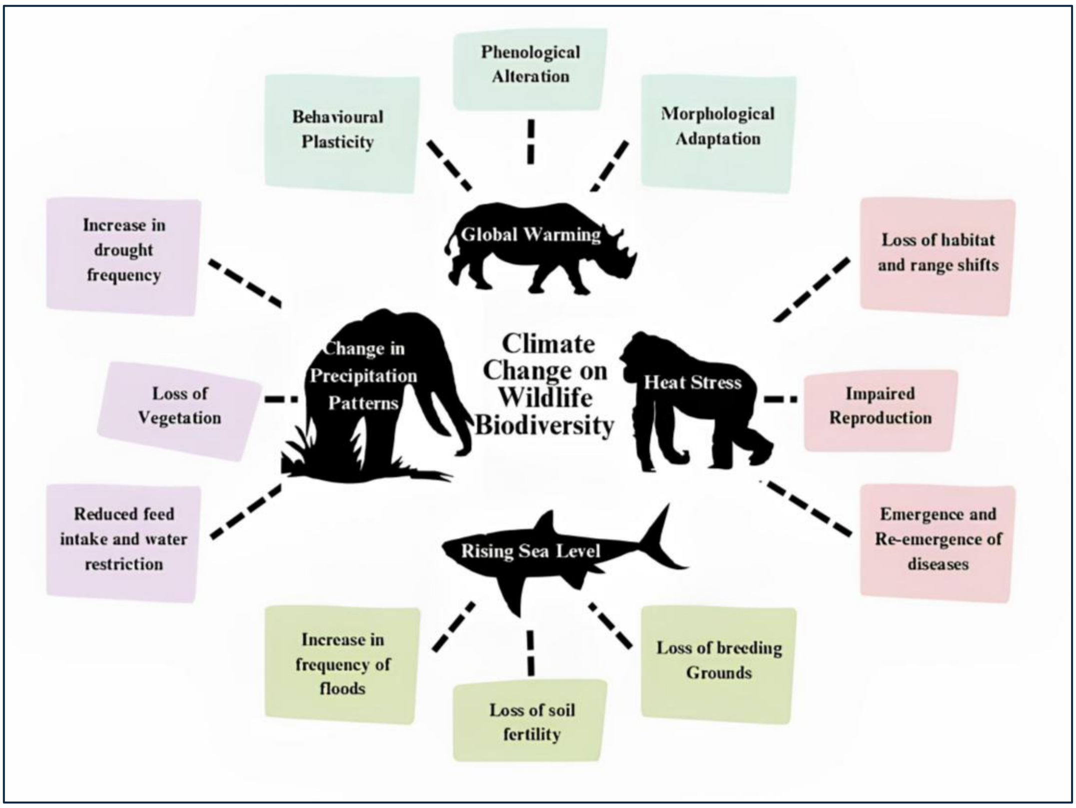

Figure: 1: The direct and indirect impacts of climate change on wildlife biodiversity. This figure describes in detail the various direct impacts, such as behavioural plasticity, phonological alteration, morphological adaptation, reduced feed intake, impaired reproduction, and the emergence of new diseases. The indirect impact includes loss of habitat and range shifts, loss of vegetation, increase in drought frequency, increased flood, loss of soil fertility, and loss of breeding ground.

Direct impacts of climate change on wildlife biodiversity

Climate change is a key driver for latitudinal and altitudinal shifts of species distribution, changes in species richness and composition, and contributes to the outbreak of plant and animal diseases (Wudu et al., 2023). Direct impacts are those attributed directly to climate change, global warming, changes in precipitation, and/or rising sea levels. This section deals with the direct impacts of climate change and global warming on the speciation, distribution, and adaptation of various wildlife species.

Global warming and heat stress

Human-induced greenhouse gas pollution due to large-scale burning of fossil fuels since the industrial revolution is a major cause of global warming and has resulted in an increase in the Earth's surface temperature by 0.6°C in the last 100 years (Walther et al., 2002). Atmospheric temperature has profound effects on the behavior, physiology, growth, reproduction, and survival of species, and on a larger scale, it affects species distribution, speciation, and evolution (Elmore et al., 2017).

Alteration of behavior in wildlife in response to increased atmospheric temperature is elicited before changes in population distribution. These behavioral responses include shade seeking, altered feeding or hunting time, and changes in the circadian or circannual rhythm. A study conducted by Rabaiotti and Woodroffe (2019) on African wild dogs (*Lycaon pictus*), naturally crepuscular animals, showed increased nocturnal hunting activity during periods with high daytime temperatures. In Death Valley, North American wood rats (*Neotoma lepida*) have altered their activity when the night-time ambient temperature falls below their lethal physiological threshold (42°C) (Murray and Smith, 2012). However, this behavioral alteration may restrict the foraging/hunting and reproductive activities.

The most common morphological adaptation to increasing atmospheric temperature is a change in body size. Norwegian red deer (*Cervus elaphus atlanticus*) born after warm winters had a considerable reduction in body size when compared to those born after cold winters (Post et al., 1997). Ectotherms, whose metabolism is temperature sensitive, have faster growth rates in warmer climatic conditions but relatively smaller body sizes, as seen in the case of the American lobster (*Homarus americanus*) (Le Bris et al., 2017).

Phenological alterations in response to climate change are well documented in various species. Spring appearance dates in 18 species of butterflies have advanced by 2.8 to 3.2 days per decade over the past 23 years (Forrest, 2016). Traditional early-breeding frogs faced increased predation due to the early entry of predatory newts into ponds (Walther et al., 2002). A study of European plant species revealed that flowering and leafing have advanced by an average of 1.4 to 3.1 days per decade due to global warming (Walther et al., 2002).

Heat stress has serious impacts on the breeding and reproductive physiology of various animals, including impaired spermatogenesis and oogenesis, oocyte maturation, fertility, early embryonic and foetal development, and lactation (Hansen, 2009; Aulsebrook et al., 2020). In various species, including amphibians, reptiles, and fish with temperature-dependent sex determination, global climate change can skew the sex ratio in the population Aulsebrook et al. (2020). Sea turtles are a prime example of this, as higher nest temperatures skew the sex ratio towards females (Fuentes et al., 2009). This imbalance may become more severe as global Climate change progresses.

The increase in ambient temperature is causing a large-scale shift in the species distribution and abundance in both terrestrial and aquatic ecosystems (Pacifici et al., 2017). In Canada, the red fox has expanded its range northward with a consequent retreat in the range of the arctic fox (Walther et al., 2002). Several species of butterflies have shifted their range poleward and upward in elevation as temperature rises in Europe and North America (Parmesan et al., 1999). Treelines on mountain slopes also show a shift upward in elevational distribution, and some alpine species have shown an average shift of 1 to 4 meters per decade (Walther et al., 2002).

Rising sea levels

Global warming is leading to the thermal expansion of ocean waters and the melting of glaciers and polar ice sheets, which has consequently increased the rate of the rise in sea level. In the last century, there has been an increase in the sea level from 1 to 2 mm per year, and the current rates have increased to 3 to 4 mm per year (IPCC, 2019). This rise in sea level due to global warming can affect the wildlife biodiversity and habitats in low-lying coastal areas (Mukul et al., 2019) and consequently increase the likelihood of coastal flooding, loss of coastal land, and salinization of freshwater wetlands (LaFever et al., 2007).

The effects of rising sea levels on coastal wildlife are loss of nesting grounds for shorebirds and sea turtles, habitat loss, range shifts, inundation of freshwater, and increased frequency of storms. Storm surges cause frequent washing off of shorebird and seabird nests (Von Holle et al., 2019). Birds nesting in low-lying coastal areas, such as the little Kingfisher (*Alcedo pusilla pusilla*) in the Torres Strait, are threatened by flooding and erosion due to rising sea levels (Garnett and Crowley, 2000). Saltwater inundation halts embryonic development and results in failure to produce hatchlings in sea turtles (Von Holle et al., 2019). A study conducted by Mukul et al. (2019) in the Bangladesh Sundarbans showed that there may be a drastic loss of the endangered Bengal tiger (*Panthera tigris tigris*) habitat, and projections suggest that by 2070, there may be a complete loss of suitable Bengal tiger habitats in the Sundarbans.

Alteration of precipitation patterns

Anthropogenic activities are aiding the drivers of global climate change, resulting in changes in the structure and function of ecosystems. A consequence of such a change is the increase in the variability of precipitation, characterized by extreme precipitation events and longer dry periods (Thomey et al., 2011). Altered precipitation patterns, potentiated by rising atmospheric temperatures, have increased the magnitude and frequency of extreme events such as droughts, flooding, storms, and wildfires.

Precipitation variability has led to an increase in the frequency and intensity of droughts throughout the globe. Between 1951 and 2010, the precipitation data collected from the Global Precipitation Climatology Centre (GPCC) showed positive trends in the frequency, intensity, and duration of droughts in Western Africa, East Asia, the Amazon, the Mediterranean, and Central America (Spinoni et al., 2013). Droughts weaken the forest defenses and make them susceptible to various pathogens, invasive species, and wildfires.

Due to the factors discussed above, there is a tremendous loss of global wildlife biodiversity and viable ecosystems. Unless adequate mitigation measures are carried out on a war footing, there can be a drastic decline in the utilitarian value and ecosystem services, with severe implications for human welfare.

Indirect impacts of climate change on wildlife biodiversity

The progressing effects of global climate change have severe consequences on various ecosystems, which will, in turn, hamper the quality and efficiency of the associated ecosystem services. These effects of climate change are due to changes in the ecosystem and ecosystem services, which are indirect impacts. Below is a detailed discussion of these impacts.

Loss of habitat, soil fertility, and vegetation

All species thrive in a particular ecological niche, with some species being more adaptable to variable climatic conditions than others. The decline in the quality of wildlife habitats, areas that provide essential services like shelter and forage for the sustainability of wildlife populations, is a concerning consequence of improper utilization of biological resources, poor land use practices, and climate change worldwide (Kija et al., 2020).

Tropical forests are key habitats to almost two-thirds of all terrestrial species, cover about 12 percent of the Earth's ice-free surface (Barlow et al., 2018), and play a crucial role in the planet's ecosystem, primary production, and climate regulation. Anthropogenic disturbances, along with progressing climate change, have resulted in an increased frequency of extreme climatic events such as floods, hurricanes, droughts, and wildfires, resulting in diminished plant growth, species shifts, reduced primary production, and a decrease in overall ecosystem resilience and stability (Franca et al., 2020).

Among the marine ecosystems, coral reefs hold the highest species diversity and provide coastal protection against natural calamities, although they occupy only 0.1% of the ocean surface (Franca et al., 2020). Elevated ocean temperatures due to climate change have resulted in mass coral bleaching and are a major contributor to increased coral mortality rates and degradation of coral reef ecosystems globally. The eventual death of bleached coral reefs leads to a decline in the abundance of obligate coral-feeding fishes due to prey availability constraints (Pratchett et al., 2018).

In the Arctic Circle, the effects of anthropogenic climate change are experienced twice as fast as in the rest of the world, causing a visible decline in sea ice due to global warming (Pagano and Anthony, 2021). The Arctic sea ice has declined by approximately 14% over the last 40 years, and sea ice thickness has declined by about 40 to 60% (IPCC, 2019; Chen, 2022), resulting in grave consequences for the Arctic wildlife species. Polar bears (*Ursus maritimus*) and ringed seals (*Pusa hispida*) depend on sea ice for traveling, foraging, hunting, resting, and breeding grounds. Bowhead whales utilize packed ice as nurseries and feeding grounds, and ice floes act as barriers from predators (Florko et al., 2020). Thus, the reduction in sea ice leads to the loss of vital habitat for many marine mammals.

Global warming and the alteration of global and local precipitation patterns have an adverse effect on the functionality of soils through impacts on hydrological, carbon, and nitrogen cycles (Al-Tawaha et al., 2021). The anticipated consequences of climate change on soil fertility are mainly due to a rise in soil temperature and alteration of soil moisture and carbon dioxide levels. The adverse effects of climate change on soil fertility are reduced water retention, salinization of soil, reduced nutrient availability, and altered carbon and nitrogen dynamics, leading to loss of soil biodiversity (Mondal et al., 2021).

Climate is an important determinant of plant species distribution and vegetation cover. Rapid climate change might lead to tremendous changes in the distribution of plant species, thus modifying vegetation structure and composition, habitats, and biomes (Sykes et al., 2009). In the Mediterranean forests, there may be an upward shift toward higher altitudes, expansion of semi-arid forests, and a reduction in broadleaf forests, while cold gymnosperm forests might face a drastic reduction in their expansion range (Solomou et al., 2017).

Reduced food availability and water restriction

The impacts of climate change on the nutrition of wildlife species are complex and, owing to the interactions at various trophic levels, are largely unclear. Changing climate has anticipated effects on the performance of wildlife, directly or indirectly, by altering the availability and composition of food (Birnie-Gauvin et al., 2017). Elevated carbon dioxide levels are associated with an increase in the tissue carbon present in plants and a consequent decrease in other nutrients (Loladze et al., 2002). Insects feeding on these plants showed reduced growth rates but elevated consumption rates, indicating a diminished nutritional quality (Birnie-Gauvin et al., 2017).

In the Antarctic, there has been a drop in the krill population by approximately 80% since the 1970s. Krill is an important source of food, and a decline threatens the survival of species whose diet comprises krill, like whales, narwhals, seals, and penguins (Mohammed, 2019). The reduction in krill numbers is attributed to the loss of sea ice, which is foraging grounds for krill, due to global warming (Sidder, 2018).

As global weather patterns continue to shift, scarcity of water is becoming a prime challenge, especially in areas prone to drought or erratic rainfall patterns. In arid ecosystems, the unavailability of natural water is a rising concern and is considered a limiting factor for species, especially large herbivores (Chakuya et al., 2021). In Southern Africa, severe droughts have resulted in water scarcity for wildlife species, making it necessary to provide artificial game water in the form of drilled boreholes. Artificial game water supply helps reduce summer mortality in wildlife species, attracts game for viewing, and prevents the concentration of large herbivores like elephants and rhinos around permanent water bodies (Chakuya et al., 2021).

Droughts change the water flow in rivers and streams, consequently affecting the movement of aquatic species, their reproduction, and their ability to orient themselves for effective navigation (Williams, 2006). Water scarcity also affects the availability of mineral nutrition to trees by altering the mineral composition in soil and the physiological mechanisms for nutrient uptake by the roots, thus adversely affecting their physiological performance, reproduction, and competitive ability (Kreuzwieser and Gessler, 2010).

Emergence and re-emergence of diseases

Emerging infectious diseases are defined as diseases that have increased their incidence in a population or geographic range, caused by a newly evolved pathogen, affected a new host population, or novel diseases that have been recently discovered (Morse, 2001). The present changes in disease epidemiology because of global climate change are mainly due to changes in the ecological processes, population susceptibility, and increased contact with pathogenic agents (Ghazali et al., 2018). The wild species may be affected by significant diseases or act as reservoirs for pathogens without causing any overt illness (Williams et al., 2002).

Anthropogenic alterations of ecosystems create suitable conditions for the emergence and transmission of diseases. The outbreak of the Duck Plague at Lake Andes, USA, in 1973, caused by duck plague virus, a herpes virus, resulting in tremendous mortality of ducks and geese, is a prime example (Wobeser, 1997). Another similar incidence at Etosha National Park, Namibia, occurred due to the installation of artificial waterholes, which increased the incidence of anthrax among large wild mammals (Lindeque and Turnbull, 1994). Climate change and shifting environmental conditions can enable pathogens to expand their host range and cross species barriers, leading to infections in previously unexposed populations. In areas where livestock and wildlife interact, particularly along the edges of protected habitats, there is an increased risk of disease transmission in both directions. A notable example is the Rinderpest outbreak in Africa during the 1980s, where the virus spilled over into wild, ungulate populations, causing significant mortality (Morens et al., 2011).

Alteration of migratory patterns

Migration is defined as a behavioral strategy that aids in acquiring suitable resources during periods of unavailability through seasonal movement and to avoid predation or adverse climatic conditions (Mikle et al., 2019). Migrating species are especially susceptible to the effects of climate change due to their interactions with the environment. Climate change alters habitats, availability of resources, and species phenology, which in turn alters the migration patterns of various species and may even cease the migration of some species (Moore, 2011).

Phenological alterations have adverse effects on migratory species. A classic example of this is the oak-Winter moth-Great Tit system, where if the Winter moth (*Operophtera brumata*) caterpillars hatch early, there is a scarcity of young leaves, but if they hatch too late, there is the presence of too many tannins in the leaves. Likewise, the hatching of Great Tits (*Parus major*) must coincide with the highest population of Winter moth caterpillars to provide enough food for the hatchlings (Bonamour, 2021).

In aquatic ecosystems, warming oceans are shifting suitable bioclimatic zones poleward, resulting in longer journeys and reduced feeding opportunities for marine species such as Baleen whales, which migrate between tropical and polar waters (Learmonth et al., 2006). In some species, the cessation of migration occurs, as in the case of the Canada goose (*Branta canadensis*) in the United States and the White stork (*Ciconia ciconia*) in Spain. These species have taken up permanent residence in areas that were previously stopover sites (Moore, 2011). Climate change has cascading effects on the global wildlife biodiversity and their ecosystems, which warrants immediate implementation of various strategies to curb these effects. The various adaptive strategies followed by wildlife species to the changing global climatic scenario are summarized in Table 1.

Mitigation strategies for the conservation of wildlife biodiversity

Climate change and global biodiversity loss are closely interconnected challenges that pose significant threats to both environmental stability and the health of humans and wildlife. These dual crises contribute to ecosystem disruption, undermining the ecological processes essential for a functional and balanced environment. Large-scale species extinctions weaken ecosystem functionality, stability, and resilience, with serious consequences for both animal and human life (Hannah et al., 2005; Cardinale et al., 2012). Therefore, understanding, predicting, and mitigating the impacts of climate change on wildlife biodiversity is vital to halt further biodiversity loss and its associated negative effects. Deforestation and degradation of tropical and sub-tropical forests for agricultural expansion and biofuel production have adversely affected global biodiversity as well as carbon stocks (Shin et al., 2022). Re-forestation with indigenous species is beneficial in restoring degraded environments, addressing biodiversity loss, and restoring carbon stocks (Edwards et al., 2021). The use of non-indigenous monoculture plantations for reforestation poses great risks to the natural environment and native biodiversity (Lewis et al., 2019). However, these practices are being financially incentivized (Shin et al., 2022). Reducing the rate of deforestation, along with reforestation of targeted areas, suitable for maintaining forest habitat continuity, can be effective in mitigating the effects of climate change on global biodiversity. Nature-based solutions such as the protection of intact ecosystems, managing agricultural lands, and restoring native cover could be thought of as some of the important measures for climate change mitigation and biodiversity protection (Wudu et al., 2023).

Coastal marine ecosystems have faced extensive degradation due to changes in land use and other anthropogenic activities, leading to habitat loss and a decline in valuable ecosystem services. Ecological restoration and reconstruction of coastal ecosystems are crucial to mitigating biodiversity losses. Reducing over-fishing, preventing invasive species, introducing native vegetation, preventing over-exploitation of coastal services, and reducing chemical pollutants are strategies implemented to enhance the marine ecosystem's health (Goreau and Hilbertz, 2005). A review of the restoration costs of several coastal ecosystems revealed that coral reefs and seagrasses were among the most expensive to restore, while mangroves were the least expensive. However, the highest survival rates were reported in salt marshes and coral reefs as opposed to seagrasses. It was concluded that the success of restoration depended on the ecosystem, site selection, and techniques applied, as well as long-term monitoring of these projects is essential for understanding the potential of restoration projects as a tool for mitigation (Bayraktarov et al., 2016).

Table 1: Adaptive strategies followed by various wildlife species to changing climatic scenario

Adaptive strategies	Species	References
Morphological adaptation		
• Reduction in body size	Norwegian red deer (*Cervus elaphus atlanticus*)	Post et al. (1997)
• Faster growth rates in warm climates	American lobster (*Homarus americanus*)	Le Bris et al. (2017)
Behavioural adaptation		
• Increased nocturnal hunting activity during periods with high daytime temperature	African wild dogs (*Lycaon pictus*)	Rabaiotti and Woodroffe (2019)
• Altered their activity when the night-time ambient temperature falls below their lethal physiological threshold (42°C)	North American wood rats (*Neotoma lepida*)	Murray and Smith (2012)
• Skewed the sex ratio	Marine turtles	Fuentes et al. (2009)
Phenological alteration		
• Spring appearance dates advanced by 2.8 to 3.2 days per decade over the past 23 years	Butterflies (18 species)	Roy and Sparks (2000); Forrest (2016)
• Flowering and leafing have advanced by an average of 1.4 to 3.1 days per decade due to global warming	Various European plant species	Walther et al. (2002); Kannan and James (2009)
• Change in the time of breeding	Tree swallows (*Tachycineta bicolor*)	Dunn and Wrinkler (1999)
Range shifts		
• Increase or decrease in the home range	Red fox (*Vulpes vulpes*) and Arctic fox (*Vulpes lagopus*)	Walther et al. (2002); Kannan and James (2009)
• Poleward and upward shift in range	Butterflies (many species)	Paramesan et al. (1999); Root and Schneider (2002)
Alteration in migration pattern		
• Cessation of migration	Canada goose (*Branta canadensis*) and White stork (*Ciconia ciconia*)	Moore (2011).
• Migratory plasticity	Elk (*Cervus canadensis*)	Rickbeil et al. (2019); Xu et al. (2021)

Permafrost covers approximately 25% of the terrestrial area in the northern hemisphere and is highly sensitive to climate change (Yang et al., 2010). This perennially frozen ground is a reserve of carbon, possessing twice as much carbon as the atmosphere, and the degradation of this layer results in the release of large quantities of carbon stored in the arctic soil, biogenic carbon dioxide, and methane emissions (Bruhweiler et al., 2021; Shin et al., 2022). Ecosystem-based management, such as the expansion of shrub cover in the Arctic region, may reduce the summer permafrost thaw and thus partially offset the degradation of permafrost (Blok et al., 2010). Restoration of peatlands and conserving undamaged peatlands can stabilize the permafrost and prevent its degradation (Minayeva et al., 2018). The preservation of permafrost can play a significant role in mitigating the effects of climate change on global biodiversity by limiting methane emissions and reducing the rate of global warming. Since permafrost stores vast amounts of organic carbon, its thawing can release large quantities of methane, a potent greenhouse gas, into the atmosphere. Preventing or slowing permafrost degradation helps curb these emissions, thereby contributing to climate stabilization and the protection of ecosystems and species vulnerable to rapid environmental changes.

Currently, global biodiversity loss is an issue of concern that the world is facing, and the promotion of research and development of novel technology to mitigate this loss is of utmost importance. Microbiome-targeted interventions such as probiotics and microbiome transplants may be effective in mitigating biodiversity loss as well as increasing the resilience of wildlife and ecosystems (Peixoto et al., 2022). Kideghesho (2009) explored the possibilities of promoting traditional African cultural practices to prevent over-exploitation of wildlife resources and habitat loss in Tanzania and found that the inclusion of native communities in conservation strategies and the use of cultural practices are effective in mitigating global wildlife loss.

The effectiveness of mitigation programs largely depends on the extent of ecosystem damage and the selection of appropriate techniques. Mitigation strategies must be community-inclusive, incentivized, and prioritized. Understanding the natural processes and customizing the strategies for different ecosystems is essential in maximizing the efficiency of mitigation programs. Wildlife biodiversity is deteriorating at an alarming rate due to climate change, and the implementation of these mitigation strategies by governments and other local bodies is crucial to preventing further destruction.

Conservation strategies for preventing wildlife biodiversity loss

Wildlife biodiversity is an important component of all ecosystems and is required for various ecological processes, yet the understanding of the impact of wildlife biodiversity loss is severely lacking. All flora and fauna, including human beings, are interconnected, and the loss of one species might have a cascading effect on the dependent species, directly or indirectly. Over the decades, climate change and overexploitation of natural resources have led to a tremendous loss in global biodiversity (Noss et al., 2015). According to Wang et al. (2024), biodiversity conservation faces multifaceted challenges, and there is an urgent need to develop adaptive and resilient management strategies in the context of escalating climate change. Sutherland et al. (2025) highlighted 15 issues concerning global biodiversity conservation that should be addressed in order to have a better outcome on biological diversity. The implementation of conservation strategies is pivotal in preserving the existing biodiversity and the associated ecosystem services for future generations.

Increase the extent of protected areas

The backbone of conservation efforts is the protected areas, both terrestrial and aquatic areas, legally designated for long-term conservation of wildlife biodiversity (Pringle, 2017). Despite the increase in the extent of these protected areas over the last four decades, research shows that the existing global network of protected areas is inadequate in preventing the continued depletion of wildlife biodiversity (Jenkins et al., 2015). Strategic management of protected areas tailored to their specific biodiversity is important in the collective performance of the global network of protected areas (Le Saout et al., 2013). Thus, the extension of protected areas overlapping endangered ecosystems and habitats of species at risk of extinction, as well as the restoration and proper management of already existing protected areas, must be a priority to decelerate the current rate of wildlife biodiversity loss.

The success of conserving protected areas lies in reducing anthropogenic pressures in ecologically diverse areas with valuable ecosystem services. As per the United Nation Environment Program (UNEP) Protected Planet report, 17% of the terrestrial and inland water and 10% of the coastal marine areas that harbor important biodiversity and ecosystem services are well conserved by protected areas and other effective area-based conservation measures (OECMs). However, 33.8% of terrestrial and inland waters and 33.9% of areas, the marine regions, which are key biodiversity areas, lack any coverage under protected areas or OECMs (UNEP, 2020). Expanding the coverage of protected areas and OECMs to include these key biodiversity hotspots is essential for the effective conservation of wildlife biodiversity and the associated ecosystem services.

Species-specific conservation strategies

Species-specific conservation strategies include actions that intend to restore or conserve a particular species, where conservation and management strategies are targeted at the individual species. These include focusing conservation resources on critically endangered species, establishing captive populations of species at risk of extinction, and reducing the anthropogenic pressures on endangered species (Mawdsley et al., 2009). Understanding and assisting wildlife reproduction is crucial in the conservation of at-risk species but may be hindered due to the lack of fundamental knowledge, limited access to wild species, and financial constraints (Le Gac et al., 2021).

Captive breeding programs play a vital role in the conservation of critically extinct and endangered species. An example of this is the recovery of the Guam Rail (*Hypotaenidia owstoni*), a flightless bird declared extinct in the wild, through a 35-year captive breeding program that has now successfully established a population in the Cocos Islands. Despite the conservation efforts, the Guam Rail is still considered critically endangered.

Assisted reproductive technology (ART) is considered an effective conservation tool for wild animal species that are on the brink of extinction. Apart from routine techniques such as artificial insemination and *in-vitro* fertilization, novel technologies relying on somatic and stem cells are potential alternatives for the future of conservation (Mastromonaco and Songsasen, 2020). The black-footed ferret (*Mustela nigripes*), endemic to North America, was thought to be extinct until 1981 when a small population was rediscovered. This population was captured for conservation breeding between 1996 and 2008; around 140 kits were produced by laparoscopic artificial insemination using fresh or frozen semen after induced ovulation (Santymire et al., 2014).

The various conservation strategies have their benefits. Figure 2 describes the various strategies to conserve wildlife biodiversity. While protected areas and OECMs are beneficial to a broader range of species, captive breeding programs and ARTs are more efficient for the conservation of critically endangered species. The success of conservation programs lies in the selection of strategies targeting a specific ecologically diverse area and the adequate management of these programs in terms of both conservation and financial resources. The recent understanding of the effects of climate change on biodiversity loss paves the way for more research and development of additional conservational approaches to manage these effects systemically. Wang et al. (2024) postulated that forecasting climate change impacts on biomes and slow policy responses are the major factors that act as barriers to biodiversity preservation efforts.

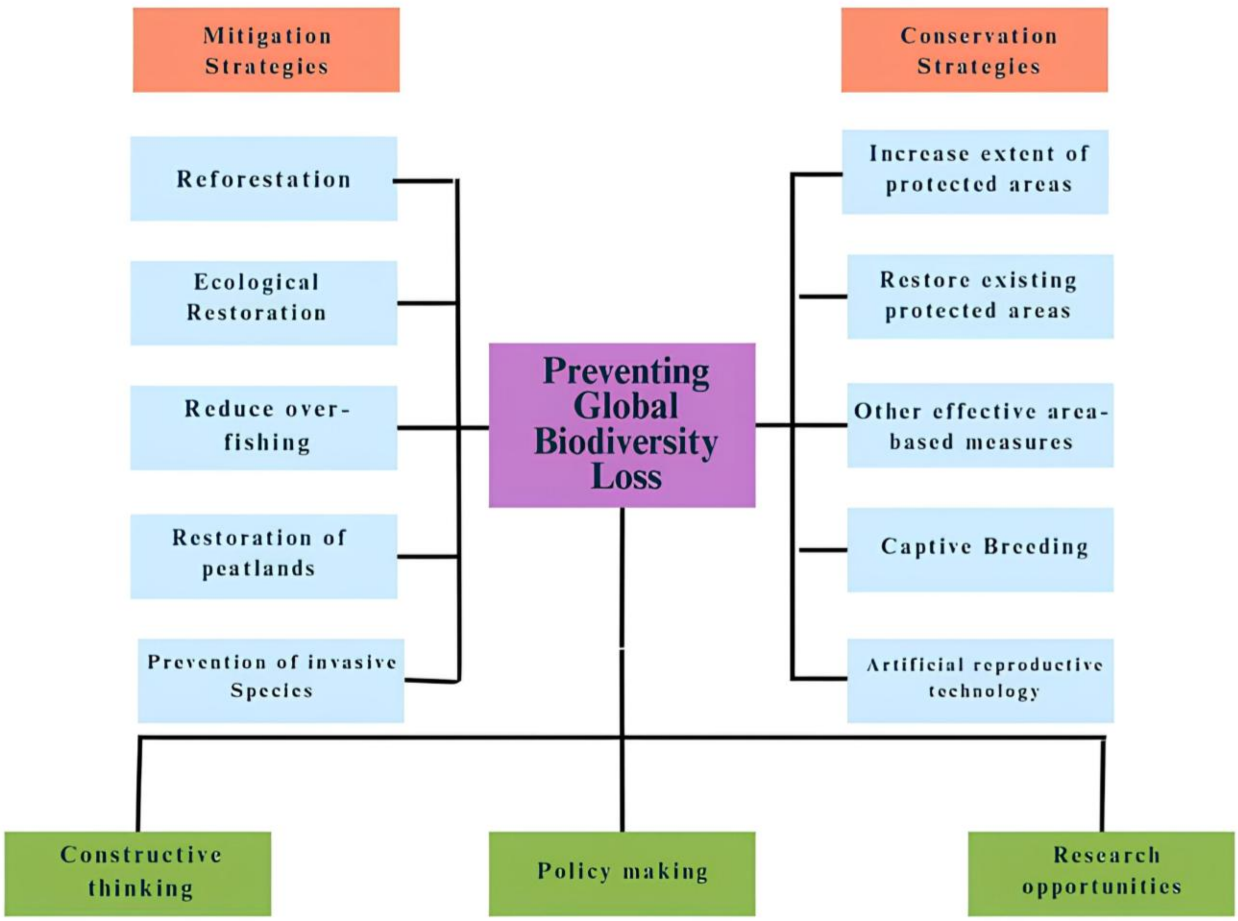

Figure 2: Different strategies for conserving wildlife biodiversity. This includes both mitigation and conservation strategies. The other strategies include constructive thinking, policy making, research opportunities, and preventing global biodiversity loss.

Conclusion

Climate change has various direct and indirect impacts on global biological diversity, which exacerbate the effects of already existing threats on wildlife biodiversity due to unregulated and exploitative anthropogenic activity. The shifting climatic conditions affect the spatial distribution of various species, population trends, behavior, reproduction, genetic variability, and the survivability of species, which, in some cases, lead to extinction. The future potential value of biodiversity is uncertain but definitely greater than the current predicted value. Hence, it must be conserved from degradation due to both climate change and anthropogenic stressors. Loss of wildlife biodiversity disrupts the delicate balance in ecological functions and essential ecosystem services that are important for the survival of human society. However, there is a lack of information regarding the impacts of climate change on the species distribution, behavior of wildlife species, habitat range, migration patterns, and occurrence of epidemics, which is vital for the planning and implementation of wildlife conservation activities and mitigation strategies. Thus, further research on the impacts of climate change on wildlife biodiversity and novel mitigation strategies, as well as raising awareness at the grassroots level, is crucial in preserving global wildlife biodiversity.

Future perspectives

As global climate change continues to progress, the primary concern of scientists, conservationists, and policymakers is the implementation of mitigation strategies to retard the rate of biodiversity loss and conserve the existing ecologically diverse areas effectively. To do so, a better understanding of the relationship between species and their ecosystem and their response to changing climatic conditions is necessary. Conservation and sustainable use activities must be identified and properly implemented, and their effectiveness in conserving wildlife biodiversity must be regularly assessed. The development of regional climate models and the use of reliable climate change scenarios to predict the vulnerability of the ecosystem and associated biodiversity can be helpful in charting mitigation strategies specifically tailored to different regions. The overall understanding of the impacts of climate change on wildlife biodiversity and the application of various mitigation efforts to retard the rate of biodiversity loss is the need of the hour. Identifying the information and assessment gaps regarding the impacts of climate change on wildlife biodiversity and the effects of biodiversity on climate change is vital in the development of monitoring systems, mitigation strategies, conservation and sustainable use activities, and policy making.

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References

Alho, C.J.R., 2008. The value of biodiversity. Brazilian Journal of Biology 68,1115–1118. http://www.10.1590/s-69842008000500018.

Al-Tawaha, A.R.M., Günal, H., Křeček, J., Zamfir, R.H.C., Patel, K.K., Vyas, R.V., et al., 2021. Soil fertility decline Under Climate Change. In: Sustainable Soil and Land Management and Climate Change. 1st ed. 127–145. CRC Press, Florida.

Aulsebrook, L.C., Michael, G.B., Jake, M.M., Anne, E.A., Brodin, T., Evans, J.P., et al., 2020. Reproduction in a polluted world: Implications for Wildlife. Reproduction 160, R13–R23. http://www.10.1530/REP-20-0154.

Barlow, J., França, F., Gardner, T.A., Hicks, C.C., Lennox, G.H., Berenguer, E., et al., 2018. The future of hyper-diverse tropical ecosystems. Nature 559, 517–526. http://www.10.1038/s41586-018-0301-1

Bayraktarov, E., Saunders, M.I., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J., et al., 2016. The cost and feasibility of marine coastal restoration, Ecological Applications 26, 1055–1074. http://www.10.1890/15-1077

Beaumont, L.J., Pitman, A., Perkins, S., Zimmermann, N.E., Yoccoz, N.G., Thuiller, W., 2011. Impacts of climate change on the world's most exceptional ecoregions. Proceedings of the National Academy of Sciences 108, 2306–2311. http://www.10.1073/pnas.1007217108

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., Courchamp, F., 2012. Impacts of climate change on the future of biodiversity. Ecology Letters 15, 365–77. http://www.10.1111/j.1461-0248.2011.01736.x

Birnie-Gauvin. K., Peiman, K.S., Raubenheimer, D., Cooke. S.J., 2017. Nutritional physiology and ecology of wildlife in a changing world. Conservation Physiology 5, 1–18 http://www.10.1093/conphys/cox030

Blok. D., Heijmans, M.M., Schaepman-Strub, G., Kononov, A.V., Maximov, T.C., Berendse, F., 2010. Shrub expansion may reduce summer permafrost thaw in Siberian tundra. Global Change Biology 16, 12961305. http://www.10.1111/j.13652486.2009.02110.x

Bonamour, S., 2021. Great tit response to climate change.

National Climate Change 11, 807–808. http://www.10.1038/s41558-021-01160-0
Bruhwiler, L., Parmentier, F.W., Crill, P., Palmer, P.I., 2021. The Arctic carbon cycle and its response to changing climate. Current Climate Change Report 7, 14–34. http://www.10.1007/s40641-020-00169-5
Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P. et. al., 2012. Biodiversity loss and its impact on humanity. Nature 486, 59–67. http://www.10.1038/nature11148
Chakuya J., Mandisodza-Chikerema, R., Ngorima, P., Malunga, A., 2021. Water sources during drought period in a Savanna wildlife ecosystem, northern Zimbabwe. Geology, Ecology, and Landscapes 7, 323–328. http://www.10.1080/24749508.2021.1971413
Chen, J., 2022. Impacts of sea ice loss on Polar bear diet, Prey availability, foraging behaviours, and human-bear interactions in the Arctic. https://repository.usfca.edu/capstone/1350
De Frenne, P., Rodríguez-Sánchez, F., Coomes, D.A., Baeten, L.., Verstraeten, G., Vellend, M. et al., 2013. Microclimate moderates plant responses to macroclimate warming. Proceedings of the National Academy of Sciences 110, 18561–18565. https://doi.org/10.1073/pnas.1311190110
Díaz, S., Settele, J., Brondízio, E., Ngo, H.T., Guèze, M.., Trinidad, J., et al., 2019. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366, eaax3100. http://www.10.1126/science.aax3100
Dirzo, R., Young, H.S., Galetti, M., Ceballos, G., Isaac, N.B.J., Collen, B., 2014. Defaunation in the Anthropocene. Science 345, 401–06. http://www.10.1126/science.1251817
Dobson, A., Jolly, A., Rubenstein, D., 1989. The Greenhouse effect and biological diversity. Tree 4, 64–67.
Dunn, P.O., Wrinkler, D.W., 1999. Climate change has affected the breeding date of tree swallows throughout North America. Proceedings of the Royal Society, London. 2487–2490. http://www.10.1098/rspb.1999.0950
Edwards, D.P., Cerullo, G.R., Chomba, S., Worthington, T.A., Balmford, A.P., Chazdon, R.L., et al., 2021. Upscaling tropical restoration to deliver environmental benefits and socially equitable outcomes. Current Biology 31, 1326–1341. http://www.10.1016/j.cub.2021.08.058
Elmore, R.D., Carroll, J.M., Tanner, E.P., Hovick, T.J., Grisham, B.A., Fuhlendorf, S.D., et al., 2017. Implications of the thermal environment for terrestrial wildlife management. Wildlife Society Bulletin 41, 183–193. http://www.10.1002/wsb.772
Florko, K., Thiemann, G.W., Bromaghin, J.F., 2020. Drivers and consequences of apex predator diet composition in the Canadian Beaufort Sea. Oecologia 194, 51–63. http://www.10.1007/s00442-020-04747-0
Forrest, J.R., 2016. Complex responses of insect phenology to climate change. Current Opinion in Insect Science 17, 49 54. http://www.10.1016/j.cois.2016.07.002
França, F.M., Benkwitt, C.E., Peralta, G., Robinson, J.P., Graham, N.A., Tylianakis, J.M. et al., 2020. Climatic and local stressor interactions threaten tropical forests and coral reefs". Philosophical Transactions of the Royal Society London B: Biological Sciences 375, 20190116. http://www.10.1098/rstb.2019.0116
Franklin, S. E., 2010. Remote sensing for biodiversity and wildlife management: Synthesis and applications. McGraw-Hill Education. 1st edn, New York. https://www.accessengineeringlibrary.com/content/book/9780071622479
Fuentes, M., Maynard, J., Guinea, M., Bell, I., Werdell, P., Hamann, M., 2009. Proxy indicators of sand temperature help project impacts of global warming on sea turtles in northern Australia. Endangered Species Research 9, 33–40. http://www.10.3354/esr00224
Garnett, S.T., Crowley, G.M., 2021. The Action Plan for Australian Birds 2020. CSIRO Publishing, Melbourne. https://www.publish.csiro.au/book/7905/
Ghazali, D.A., Guericolas, M., Thys, F., Sarasin, F., Gonzalez, P.A., Casalino, E., 2018. Climate change impacts on disaster and emergency medicine focusing on mitigation disruptive effects: An international perspective. International Journal of Environmental Research and Public Health 15, 1379. http://www.10.3390/ijerph15071379
Gilg, O., Kovacs, K.M., Aars, J., Fort, J., Gauthier, G., Gremillet, D. et al., 2017. Climate change and the ecology and evolution of Arctic vertebrates. Annals of the New York Academy of Sciences 1249, 166-190. http://www10.1111/j.1749-6632.2011.06412.x
Goreau, T.J., Hilbertz, W., 2005. Marine ecosystem restoration: costs and benefits for coral reefs. World Resources Review 17, 375–409.
Hannah, L., Midgely, G.H., Bomhard, B., 2005. The view from the Cape: extinction risk, protected areas, and climate change. BioScience 55, 231–242. http://www.10.1641/00063568(2005)055[0231:TVFTCE]2.0.CO;2
Hansen, P.J., 2009. Effects of heat stress on mammalian reproduction. Philosophical Transactions of the Royal Society London B: Biological Sciences 364, 3341–3350. http://www.10.1098/rstb.2009.0131
Hof, C., Levinsky, I., Araujo, M.B., Rahbek, C., 2011. Rethinking species' ability to cope with rapid climate change. Global Change Biology 17, 2987–2990 http://www.10.1007/s1102 7-019-09891-4
IPCC., 2014. Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom, and New York, NY, USA. https://unfccc.int/topics/science/workstreams/cooperation-with-the-ipcc/the-fifth-assessment-report-of-the-ipcc
IPCC., 2019. IPCC special report on the ocean and cryosphere in a changing climate. https://www.unep.org/resources/report/ipcc-special-report
Jenkins, C.N., Van Houtan, K.S., Pimm, S.L., Sexton. J.O., 2015. U.S. protected lands mismatch biodiversity priorities. Proceedings of the National Academy of Sciences. 112, 5081–5086. http://www.10.1073/pnas.141803411
Kahraman, A., Onder, M., Ceyhan, E., 2012. The importance of bio-conservation and biodiversity in Turkey. International Journal of Bioscience, Biochemistry and Bioinformatics 2, 95. http://www.10.7763/JBBB.2012.V2.79
Kannan, R. and James, D.A., 2009. Effects of climate change on global biodiversity: a review of key literature. Tropical Ecology, 50, p.31.
Kideghesho, J. R., 2009. The potentials of traditional African cultural practices in mitigating overexploitation of wildlife species and habitat loss: Experience of Tanzania. International Journal of Biodiversity Science, Ecosystem Service Management 5, 83–94. http://www.10.1080/17451590903065579
Kija, H.K., Ogutu, J.O., Mangewa L.J, Bukombe, J., Verones, F., Graae, B.J. et al., 2020. Spatio-temporal changes in wildlife habitat quality in the greater Serengeti ecosystem.

Sustainability 12, 2440. http://www.10.3390/su12062440
Kilpatrick, A.M., 2006. Facilitating the evolution of resistance to avian malaria in Hawaiian birds. Biological Conservation 128, 475–485. http://www.10.1016/j.biocon.2005.10.014
Kreuzwieser, J., Gessler, A., 2010. Global climate change and tree nutrition: influence of water availability. Tree Physiology 30, 1221–1234. http://www.10.1093/treephys/tpq055
Kumar, M.S., Kushwaha, S.P.S., 2018. Forest resource dependence and ecological assessment of forest fringes in rainfed districts of India. Indian Forester 144, 211–220. http://www.indianforester.co.in
Kumar, M.S., Kushwaha, S.P.S., 2020. Managing the forest fringes of India: A national perspective for meeting sustainable development goals. In: Khaiter, P and Erechtchoukova, M. (eds) Sustainability Perspectives: Science, Policy and Practice. Strategies for Sustainability. Springer, Cham. http://www.10.1007/978-3-030-19550-2_16
Kumar, V., Chopra, A.K., 2009. Impact of climate change on biodiversity of India with special reference to Himalayan region-An overview. Journal of Applied Natural Science 1, 117–122. http://www.10.31018/jans.v1i1.48
LaFever, D.H., Lopez, R.R., Feagin, R.A, et al., 2007. Predicting the impacts of future sea-level rise on an endangered Lagomorph. Environment Management 40, 430–437. http://www.10.1007/s00267-006-0204-z
Le Bris, A., Pershing, A.J., Gaudette, J. Pugh, T.L., Reardon, K.M., 2017. Multi-scale quantification of the effects of temperature on size at maturity in the American lobster (Homarus americanus). Fish Research 186, 397– 406. http://www.10.1016/j.fishres.2016.09.008
Le Gac, S., Ferraz, M., Venzac, B., Comizzoli, P., 2021. Understanding and assisting reproduction in wildlife species using microfluidics. Trends in Biotechnology 39, 584-597. http://www.10.1016/j.tibtech.2020.08.012
Le Saout, S., Hoffmann, M., Shi, Y., Hughes, A., Bernard, C., Brooks, T.M. et al., 2013. Protected areas and effective biodiversity conservation. Science 342, 803–805. http://www.10.1126/science.1239268
Learmonth, J. A., MacLeod, C.D., Santos, M.B., Pierce, G.J., Crick, H.Q.P., Robinson, R.A., 2006. Potential effects of climate change on marine mammals. Oceanography and Marine Biology 44, 431–464
LeDee, O.E., Handler, S.D., Hoving, C.L., Swanston, C.W., Zuckerberg, B., 2021. Preparing wildlife for climate change: How far have we come? Journal of Wildlife Management 85, 7-16. http://www.10.1002/jwmg.21969
Lewis, S.L., Wheeler, C.E., Mitchard, E.T.A., Koch, A., 2019. Restoring natural forests is the best way to remove atmospheric carbon. Nature 568, 25–28. http://www.10.1038/d41586-019-01026-8
Lindeque, P.M., Turnbull, P.C.B., 1994. Ecology and epidemiology of anthrax in the Etosha National Park, Namibia. The Onderstepoort Journal of Veterinary Research 61, 71–83.
Loladze, I., 2002. Rising atmospheric CO2 and human nutrition: toward globally imbalanced plant stoichiometry? Trends in Ecology and Evolution 17, 457–461. http://www.10.1016/S0169-5347(02)02587-9
Lyam, P.T., Duque-Lazo, J., Hauenschild, F., et al., 2022. Climate change will disproportionally affect the most genetically diverse lineages of a widespread African tree species. Science Reporter 12, 7035. http://www.10.1038/s41598-022-11182-z
Macreadie, P.I., Jarvis, J., Trevathan-Tackett, S.M., Bellgrove, A., 2017. Seagrasses and macroalgae: importance, vulnerability and impacts. Climate change impacts on fisheries and aquaculture: A global analysis 2, 729–770. http://www.10.1002/9781119154051.ch22
Manfredo, M.J., 2008. Who cares about wildlife? In: Who Cares About Wildlife? Springer, New York, NY. https://doi.org/10.1007/978-0-387-77040-6_1
Maqbool, M.E., Sattar, Q., Ehsan, R., Akhter, S., 2021. Review on climate change and its effect on wildlife and ecosystem. Open Journal of Environmental Biology 6, 008–014. http://www.10.17352/ojeb.000021
Markham, A., Malcolm, J., 1996. Biodiversity and Wildlife: Adaptation to climate change. In: Smith J.B et al. (eds) Adapting to Climate Change. Springer, New York, https://doi.org/10.1007/978-1-4613-8471-7_33
Mastromonaco, G.F., Songsasen, N., 2020. Reproductive technologies for the conservation of wildlife and endangered species. In: Presicce G.A (ed) Reproductive Technologies in Animals. Academic Press, Cambridge. https://doi.org/10.1016/B978-0-12-817107-3.00007-2
Mawdsley, J.R., O'Malley, R.O., Ojima, D.S., 2009. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology. 23, 1080–1089. http://www.10.1111/j.1523-1739.2009.01264.x
Mikle, N.L., Graves, T.A., Olexa, E.M., 2019. To forage or flee: lessons from an elk migration near a protected area. Ecosphere. 10, e02693. http://www.10.1002/ecs2.2693
Minayeva, T., Jambaljav, Y., Dugarjav, C., Sirin, A., Tsogt-Erdene, G., Undrakhtsetseg, Y. et al., 2018. Peat land and permafrost in Mongolia: Management options for climate change mitigation and adaptation. In 5th European Conference on permafrost, June. https://hal.archives-ouvertes.fr/hal-01816115
Mittermeier, R.A., Robles-Gil, P., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C.G. et al., 2004. Hotspots revisited. CEMEX, Mexico. https://press.uchicago.edu/ucp/books/book/distributed/H/bo3707156.html
Mohammad, A., 2019. Antarctica Climate Change and how it is affecting the species living there, especially penguins. Journal of University Studies for Inclusive Research 2, 355-366. https://usrij.com/wp-content/uploads/2020/01/Antarctica-Climate-Change-and-how-it-affecting-the-species-living-there-especially-penguins..pdf
Mondal, S., 2021. Impact of climate change on soil fertility. In: Choudhary, D.K., Mishra, A., Varma, A. (eds) Climate Change and the Microbiome. Soil Biology 63: Springer. https://doi.org/10.1007/978-3-030-76863-8_28
Moore, T., 2011. Climate change and animal migration. Environmental Law. 41, 393.
Morens, D.M., Holmes, E.C., Davis, A.S., Taubenberger, J.K., 2011. Global Rinderpest Eradication: Lessons learned and why humans should celebrate too. Journal of Infectious Diseases 204, 502–505. http://www.10.1093/infdis/jir327
Morrison, M.L., Marcot, B. and Mannan, W., 2012. Wildlife-habitat relationships: Concepts and applications. 3rd edn. Island Press, Washington.
Morse, S.S., 2001. Factors in the emergence of infectious diseases. Plagues and politics. 8-26. http://www.10.1057/9780230524248_2.
Mukul, S.A., Alamgir, M., Sohel, Md. S.I., Pert, L.P., Herbohn, J., Turton, S.M. et al., 2019. Combined effects of climate change and sea-level rise project dramatic habitat loss of the globally endangered Bengal tiger in the Bangladesh Sundarbans. Science of the Total Environment 663, 830–840. http://www.10.1016/j.scitotenv.2019.01.383.

Murray, I.W., Smith, F.A., 2012. Estimating the influence of the thermal environment on activity patterns of the desert woodrat (Neotoma lepida) using temperature chronologies. Canadian Journal of Zoology 90, 1171–80. http://www.10.1139/z2012-084
Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 153–158. http://www.10.1641/006-3586(2003)053(0916:BHR).2.0.CO;2
Noss, R.F., Platt, W.J., Sorrie, B.A., Weakley, A.S., Means, D.B., Costanza, J., et al., 2015. How global biodiversity hotspots may go unrecognized: Lessons from the North American Coastal Plain. Divers Distribution 21, 236–244. http://www.10.1111/ddi.12278
Pacifici, M., Visconti, P., Butchart, S.H.M., Watson, J.E.M., Cassola, F.M., Rondinini, C., 2017. Species' traits influenced their response to recent climate change. Nature Climate Change 7, 205–208. http://www.10.1038/nclimate3223
Pagano, A.M., Williams, T.M., 2021. Physiological consequences of Arctic Sea ice loss on large marine carnivores: unique responses by polar bears and narwhals. Journal of Experimental Biology 224, p. jeb228049. http://www.10.1242/jeb.228049
Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H. et al., 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399, 579–583. http://www.10.1038/21181.
Peixoto, R.S., Voolstra, C.R., Sweet, M., Duarte, C.M., Carvalho, S., Villela, H., et al., 2022. Harnessing the microbiome to prevent global biodiversity loss. *Nature* Microbiology *7*, 1726–1735. https://doi.org/10.1038/s41564-022-01173-1
Pfenning-Butterworth, A., Buckley, L.B., Drake, J.M., Farner, J.E., Farrel, M.J., Gehman, AM., et al., 2024. Interconnecting global threats: Climate change, biodiversity loss, and infectious diseases. The Lancet 8, e270-e283. http://www.10.1016/S2542-5196(24)00021-4.
Pickett, S.T., Collins, S.L., Armesto, J.J., 1997. Models, machineries, and pathways of succession. The Botanical Review 53, 99–102. https://link.springer.com/article/10.1007/BF02858321
Post, E., Stenseth, N.C., Langvatn, R., Fromentin, J.M., 1997. Global climate change and phenotypic variation among red deer cohorts. Proceedings of the Royal Society of London B: Biological Sciences 264, 1317–1324. http://www.10.1098/rspb.1997.0182
Pratchett, M.S., Thompson, C.A., Hoey, A.S., Cowman, P.F., Wilson, S.K., 2018. Effects of coral bleaching and coral loss on the structure and function of Reef Fish assemblages. In: van Oppen, M., Lough, J. (eds) Coral Bleaching. Ecological Studies, 233. Springer, Cham pp 265–293. https://www.10.1007/978-3-319-75393-5_11
Pringle, R.M., 2017. Upgrading protected areas to conserve wild biodiversity. Nature 546, 91-99. http://www.10.1038/nature22902
Rabaiotti, D., Woodroffe, R., 2019. Coping with climate change: limited behavioral responses to hot weather in a tropical carnivore. Oecologia 189, 587–599. http://www.10.1007/s00442-018-04329-1
Rawat, U., Agarwal, N., 2015. Biodiversity: Concept, threats and conservation. Environment Conservation Journal 16, 19–28. http://www.10.36953/ECJ.2015.16303
Reid, W.V., 1998. Biodiversity hotspots. Trends in Ecology & Evolution 13, 275-280. http://www.10.1016/S0169-5347(98)01363-9
Rickbeil, G.J.M., Merkle, J.A., Anderson, G., St Clair, C.C., Fieberg, J., 2019. Plasticity in migratory behavior of a large herbivore: Changing migration strategies at a population level. Ecology 100: e02772. http://doi.org/10.1002/ecy.2772
Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M. et al., 2014. Status and ecological effects of the world's largest carnivores. Science 343, 1241484. http://www.10.1126/science.1241484
Root, T.L. and Schneider, S.H., 2002. Climate change: overview and implications for wildlife. Wildlife responses to climate change: North American case studies, 10, 765–766. https://stephenschneider.stanford.edu/Publications/PDF_Papers/Overview%281-56%29.pdf
Roy, D.B. and Sparks, T.H., 2000. Phenology of British butterflies and climate change. Global Change Biology, 6, 407-416. https://doi.org/10.1046/j.1365-2486.2000.00322.x
Santymire, R.M., Livieri, T.M., Branvold-Faber, H., Marinari, P.E., 2014. The Black-Footed Ferret: On the brink of recovery? In: Holt, W., Brown, J., Comizzoli, P. (eds) Reproductive Sciences in Animal Conservation. Advances in Experimental Medicine and Biology, Springer, New York, NY. http://www.10.1007/978-1-4939-0820-2_7
Shin, Y.J., Midgley, G.F., Archer, E.R., Arneth, A., Barnes, D.K., Chan, L. et al., 2022. Actions to halt biodiversity loss generally benefit the climate. Global Change Biology 28, 2846–2874. http://www.10.1111/gcb.16109
Sidder, A., 2016. Antarctica could lose most of its penguins to climate change". National Geographic. https://www.nationalgeographic.com/animals/article/adelie-penguins-antarctica-climate-change-population-decline-refugia
Solomou, A., Proutsos, N., Karetsos, G., Tsagari, C., 2017. Effects of climate change on vegetation in Mediterranean forests: A review. International Journal of Agriculture, Environment and Biotechnology 2, http://hdl.handle.net/20.500.12038/31.
Spinoni, J., Naumann, G., Carrao, H., Barbosa, P., Vogt, J., 2014. World drought frequency, duration, and severity for 1951–2010. International Journal of Climatology 34, 2792–2804. http://www.10.1002/joc.3875
Staudt, A., Leidner, A.K., Howard, J., Brauman, K.A., Dukes, J.S., Hanse, L.J., et al., 2013. The added complications of climate change: Understanding and managing biodiversity and ecosystems. Frontiers in Ecology and Environment 11, 494–501. http://www.10.1890/120275
Sutherland, W.J., Brotherton, P.N.M., Butterworth, H.M., Clarke, S.J., Davies, T.E., Doar, N., et al., 2025. A horizon scan of biological conservation issues for 2025. Trends in Ecology and Evolution 40, 80–89. http://www.10.1016/j.tree.2024.11.002
Sykes, M.T., 2009. Climate change impacts: Vegetation. eLS Wiley online library. https://doi.org/10.1002/9780470015902.a0021227
IUCN, 2019. Red List of Threatened Species. 2019. IUCN Red List of Threatened Species. https://www.iucnredlist.org/resources/media
Thomey, M.L., Collins, S.L., Vargas, R., Johnson, J.E., Brown, R.F., Natvig, D.O. et al., 2011. Effect of precipitation variability on net primary production and soil respiration in a Chihuahuan Desert grassland. Global Change Biology 17, 1505-1515. http://www.10.1111/j.1365-2486.2010.02363.x
Treves, A., Wallace, R.B., White, S., 2009. Participatory

planning of interventions to mitigate human–wildlife conflicts. Conservation Biology 23, 1577–1587. http://www.10.1111/j.1523-1739.2009.01242.x

Unanaonwi, E.O., Amonum, I.J., 2014. Changes in tropical forest vegetation composition: The long-term impacts. International Journal of Sustainable Development and Planning 3, 456-465. https://isdsnet.com/ijds-v3n3-4.pdf

UNEP, 2020. Protected Planet Report 2020: Tracking progress towards global targets for protected areas. UN Environment Programme and International Union for Conservation of Nature (IUCN). https://www.protectedplanet.net/en/resources/protected-planet-report-2020

U.S. Fish and Wildlife Service, 2007. 2006 National survey of fishing, hunting, and wildlife-associated recreation: National overview. Washington, DC: U.S. Fish and Wildlife Service. https://www.fws.gov/program/national-survey-fishing-hunting-and-wildlife-associated-recreation-fhwar#:~:text=The%20National%20Survey%20of%20Fishing,and%20other%20wildlife%2Drelated%20recreation

Von Holle, B., Irish, J.L., Spivy, A., Weishampel, J.F., Meylan, A., Godfrey, M.H., et al., 2019. Effects of future sea level rise on coastal habitat. Journal of Wildlife Management 83, 694–704. http://www.10.1002/jwmg.21633

Walter. V. R., 1998. Biodiversity hotspots. Trends in Ecology Evolution 13, 275-280, ISSN 0169–5347. http://www.10.1016/S0169-5347(98)01363-9

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, J.M., et al., 2002. Ecological responses to recent climate change. Nature 416, 389–395. http://www.10.1038/416389a

Wang, Z., Wang, T., Zhang, X., Wang, J., Yong, Y., Sun, Y., et al., 2024. Biodiversity conservation in the context of climate change: Facing challenges and management strategies. Science of the Total Environment 937, 173377. http://www.10.1016/j.scitotenv.2024.173377

Williams, E.S., Yuill, T., Artois, M., Fischer, J. and Haigh, S.A., 2002. Emerging infectious diseases in wildlife. Revue Scientifique et Technique Office International des Epizooties 21, 139–158. http://www.10.20506/rst.21.1.1327

Williams, J.G., 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4, http://www.10.15447/sfews.2006v4iss3art2

Wobeser, G.A., 1997. Duck Plague. In: Diseases of Wild Waterfowl. Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-5951-1_2

Wudu, K., Abegaz, A., Ayele, L., Ybabe, M., 2023. The impacts of climate change on biodiversity loss and its remedial measures using nature-based conservation approach: A global perspective. Biodiversity Conservation 32, 3681–3701. http://doi.org/10.1007/s10531-023-02656-1

Xu, W., Zang, S., Dong, W., Huang, J., 2021. The impact of climate change on animal migration. Climate Research 86, 17–30. http://doi.org/10.3354/cr01637

Yang, Z.P., Ou, Y.H., Xu, X.L., Zhao, L., Song, M.H., Zhou, C.P., 2010. Effects of permafrost degradation on ecosystems. Acta Ecologica Sinica 30, 33–39. http://www.10.1016/j.chnaes.2009.12.006