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Ecological resilience in a changing world: Challenges and opportunities in biodiversity conservation in the face of climate change

Crossref doi https://doi.org/10.56238/alookdevelopv1-176

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ABSTRACT
This chapter investigates the impacts of climate change on biodiversity and explores the conservation and adaptation strategies needed to address this global threat. Through a systematic review of the scientific literature, the study analyzes the effects of climate change at different geographical and taxonomic scales, identifying trends, patterns, and gaps in current knowledge. In addition, the adaptive responses of species and ecosystems and the implications for biodiversity conservation are discussed. Finally, the chapter presents an assessment of the most effective conservation and adaptation strategies, including in situ and ex situ measures, ecological restoration, and international policies. The aim is to contribute to the debate on the management of natural resources in the context of climate change and to guide decision-making in relation to biodiversity conservation and adaptation to climate change.

Keywords: Climate change, Biodiversity, Conservation strategies, Ecosystems.

1 INTRODUCTION

Climate change represents one of the greatest threats to the environment and society in the twenty-first century. Rising global average temperatures, changing precipitation patterns, and the intensification of extreme weather events have affected ecosystems and human communities around the world. Among the diverse impacts of climate change, the threat to biological diversity is of particular concern, given that biodiversity plays a key role in maintaining the health of ecosystems and the services they provide.

Biodiversity, defined as the variety of life in all its forms and levels of organization, is essential for the sustainability of ecosystems and for human well-being. However, human activities such as agricultural expansion, exploitation of natural resources and pollution have led to a significant loss of biodiversity worldwide. The interplay between climate change and other threats to biodiversity results in complex and urgent challenges to the conservation and management of natural resources.

In this context, this chapter seeks to examine the impacts of climate change on biodiversity and discuss the conservation and adaptation strategies needed to address this threat. The aim is to provide a comprehensive and up-to-date view of the main findings of the scientific literature, identifying trends, patterns and gaps in knowledge about climate change and biodiversity. In addition, the study aims to contribute to the debate on biodiversity conservation policies and practices in this context of profound changes in the planet's climate.

The research questions that guide this study include: (1) What are the main effects of climate change on biodiversity at different geographical and taxonomic scales? (2) How are species and ecosystems adapting to climate change, and what are the implications for conservation? (3) Which conservation and adaptation strategies are most effective in mitigating the impacts of climate change on biodiversity and ensuring the resilience of ecosystems? In addressing these issues, the chapter aims to inform and guide decision-making in relation to biodiversity conservation and adaptation to climate change.

2 LITERATURE REVIEW

2.1 CLIMATE CHANGE

A. Causes and evidence of climate change

Climate change refers to long-term changes in weather patterns and global temperatures, primarily due to anthropogenic activities such as the burning of fossil fuels, deforestation, and other industrial processes (IPCC, 2021). Over the past few decades, there has been an increase in evidence supporting the idea that human activities are contributing to these changes (Houghton et al., 2001). This section will explore the root causes of climate change, focusing on natural and anthropogenic factors, as well as the evidence supporting these claims.

A1. Natural causes of climate change

Natural causes of climate change include volcanic eruptions and the variability of solar radiation (Solomon et al., 2007). Volcanic eruptions release large amounts of aerosols and greenhouse gases, such as carbon dioxide (CO2) and sulfur dioxide (SO2), into the atmosphere. These emissions can lead to short-term cooling, as aerosols block the entry of sunlight, but also long-term warming due to increased concentration of greenhouse gases (Robock, 2000).

The variability of solar radiation, which is caused by fluctuations in the sun's production, can also affect climate change (Lean, 2000). For example, periods of increased solar activity, such as during a solar maximum, can cause the Earth's climate to warm slightly, while periods of decreased solar activity, such as during a solar minimum, can lead to cooling (Lean, 2000).

A2. Anthropogenic causes of climate change

The main driver of recent climate change is the increase in greenhouse gas emissions due to human activities (IPCC, 2021). These emissions are primarily a result of burning fossil fuels, such as coal, oil, and natural gas, for energy production, transportation, and industrial processes (Houghton et al., 2001). The combustion of fossil fuels releases CO2, a potent greenhouse gas that traps heat in the atmosphere, leading to global warming (IPCC, 2021).

Deforestation, agriculture, and other land-use changes also contribute to increased greenhouse gas emissions (IPCC, 2021). For example, deforestation releases CO2 stored in trees and soil, while livestock produces methane (CH4), another potent greenhouse gas (IPCC, 2021). In addition, nitrous oxide (N2O) emissions from agricultural activities, such as fertilizer use, contribute to the greenhouse effect (IPCC, 2021).

A3. Evidence of climate change

Numerous lines of evidence demonstrate the impacts of climate change, including changes in global temperatures, sea level rise, shrinking ice sheets, and extreme weather events.

Global temperature rise: According to the IPCC (2021), the global average temperature has increased by approximately 1.2°C since the pre-industrial era, with the last seven years being the warmest on record. This warming trend is consistent with the increase in greenhouse gas emissions due to human activities (IPCC, 2021).

Sea level rise: Sea level has risen approximately 20 cm since the early 1900s, mainly due to the thermal expansion of seawater and the melting of glaciers and ice sheets (IPCC, 2021). The rate of sea level rise has accelerated in recent decades, posing a significant threat to coastal communities and ecosystems (Church & White, 2011).

Shrinking ice sheets and glaciers: Observations of satellite data and other measurements show a decline in the extent and thickness of ice sheets and glaciers worldwide (IPCC, 2021). The Greenland and Antarctic ice sheets have been losing mass at an increasing rate, contributing to sea level rise (Shepherd et al., 2018). In addition, mountain glaciers have experienced significant retreat, with negative impacts on water resources and ecosystems in many regions (IPCC, 2021).

Extreme weather events: Climate change has been linked to an increase in the frequency and intensity of some extreme weather events, such as heat waves, heavy precipitation, and tropical cyclones (IPCC, 2021). For example, heatwaves have become more frequent and prolonged in many regions, leading to increased risks to human health, agriculture and infrastructure (IPCC, 2021). In addition, the intensity of heavy precipitation events has increased in some areas, causing more severe flooding and landslides (IPCC, 2021).

The evidence for climate change is clear and compelling, with natural factors such as volcanic eruptions and variability of solar radiation playing a role alongside anthropogenic activities such as the burning of fossil fuels, deforestation and other industrial processes. The consequences of climate change, including rising global temperatures, rising sea levels, shrinking ice sheets, and extreme weather events, are already impacting societies and ecosystems around the world. Addressing climate change requires immediate and sustained mitigation and adaptation efforts at the local, regional and global levels.

B. Impact of human activities on climate

Our planet's climate is a complex and interconnected system that has experienced significant changes throughout its history. In recent decades, a growing body of evidence has emerged, highlighting the significant impact of human activities on global weather patterns (IPCC, 2021). This section seeks to elucidate the ways in which human activities have contributed to climate change by exploring the driving factors, consequences, and potential mitigation strategies.

B1. Anthropogenic greenhouse gas emissions

The main driver of human-induced climate change is the emission of greenhouse gases (GHGs), particularly carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). These gases trap heat in the Earth's atmosphere, leading to an increase in global average temperatures, commonly referred to as global warming (IPCC, 2021). The increase of the greenhouse effect through human activities is known as the anthropic greenhouse effect, leading to global warming and climate change (DIAS, 2015)

B2. Combustion of fossil fuels

The burning of fossil fuels, such as coal, oil and natural gas, for energy production and transport has been the main source of anthropogenic CO2 emissions since the Industrial Revolution (EIA, 2020). In 2019, fossil fuels accounted for approximately 73% of global CO2 emissions (Le Quéré et al., 2020). The release of these emissions has led to a rapid increase in atmospheric CO2 concentrations, reaching levels unprecedented in at least the last 800,000 years (Lüthi et al., 2008).

B3. Deforestation and land use change

The variety of human activities that increase the greenhouse effect concerns not only CO2 and other greenhouse gas (GHG) emissions, but also systematic deforestation that reduces the forest's natural ability to absorb CO2 and incorporate it into natural cycles of energy and matter. In addition, land use change, driven primarily by agricultural expansion, has also contributed significantly to anthropogenic CO2 emissions. Forests act as carbon sinks, absorbing and storing CO2 from the atmosphere (DIAS, 2015)). When forests are cleared or degraded, stored carbon is released back into the atmosphere, exacerbating global warming (Baccini et al., 2017). In 2019, land use change was responsible for approximately 11% of global CO2 emissions (Le Quéré et al., 2020).

Methane (CH4) is another potent greenhouse gas, with a global warming potential approximately 28 times greater than that of CO2 on a 100-year timescale (IPCC, 2013). Methane emissions are primarily associated with livestock production, rice paddies, and fossil fuel extraction (Saunois et al., 2020). Nitrous oxide (N2O), with a global warming potential 265 times greater than

CO_2, is emitted mainly through agricultural activities, such as the application of nitrogen-based fertilizers (IPCC, 2013; Tian et al., 2020).

B4. Consequences of human-induced climate change

The impacts of human-induced climate change are multifaceted, affecting ecosystems, economies and human health. As global temperatures rise, the frequency and severity of extreme weather events such as heat waves, droughts, and heavy precipitation are expected to increase (IPCC, 2021). These events can lead to widespread crop failures, damage to infrastructure, and loss of life (Mora et al., 2018).

Rising global temperatures also contribute to the melting of glaciers and ice sheets, causing sea levels to rise (Rignot et al., 2019). This poses a significant threat to coastal communities, as rising sea levels increase the risk of flooding, storms, and coastal erosion (Hinkel et al., 2014).

In addition, climate change exacerbates biodiversity loss and ecosystem degradation as species struggle to adapt to rapidly changing environmental conditions (Urban, 2015). This can have cascading effects on ecosystem services such as pollination, water filtration, and carbon sequestration, which are vital to human well-being and economic stability (Cardinale et al., 2012).

In addition, human-induced climate change has implications for public health. Rising temperatures can exacerbate air pollution by facilitating the formation of ground-level ozone and increasing the concentration of airborne allergens, leading to respiratory and cardiovascular health problems (Anenberg et al., 2010). Climate change can also alter the distribution of disease vectors such as mosquitoes and ticks, expanding the geographic distribution of vector-borne diseases such as malaria and Lyme disease (Rocklöv & Dubrow, 2020).

B5. Mitigation strategies

To limit the adverse impacts of human-induced climate change, it is crucial to implement mitigation strategies aimed at reducing greenhouse gas emissions. Some of the key strategies include:

1. Transition to renewable energy sources: Replacing fossil fuels with renewable energy sources, such as solar, wind, and hydropower, can significantly reduce CO_2 emissions from electricity generation and transportation (Jacobson et al., 2017)
2. Increasing energy efficiency: Improving energy efficiency in buildings, appliances and transport can help reduce greenhouse gas emissions by reducing overall energy consumption (IPCC, 2014).
3. Sustainable land management: Implementing sustainable land management practices, such as agroforestry, reforestation, and conservation agriculture, can increase carbon sequestration and reduce emissions from land-use change (Smith et al., 2019

4. Reducing methane and nitrous oxide emissions: Improving livestock management, such as optimizing feeding and manure management strategies, along with adopting alternative rice cultivation practices in wetlands, can help mitigate methane emissions (Gerber et al., 2013; IPCC, 2019). Reducing the use of nitrogen-based fertilizers and implementing efficient fertilizer application techniques can mitigate nitrous oxide emissions (Zhang et al., 2015).

The evidence supporting the impact of human activities on the global climate is robust and compelling. Anthropogenic greenhouse gas emissions, resulting from fossil fuel combustion, deforestation and agriculture, have led to a significant increase in global average temperatures. This human-induced climate change has far-reaching consequences, affecting ecosystems, economies and public health. The implementation of mitigation strategies, such as the transition to renewable energy sources and the adoption of sustainable land management practices, is crucial to limiting the adverse impacts of climate change and safeguarding the future of the planet.

B6. Adaptation strategies

In addition to mitigation efforts, adaptation strategies are vital to reducing the vulnerability of human and natural systems to the impacts of climate change. These strategies aim to increase the resilience of communities, ecosystems and economies in the face of changing climate conditions. Key adaptation strategies include:

1. Infrastructure planning and design: Incorporating climate change considerations into the planning and design of infrastructure projects can help reduce the risk of damage from extreme weather events and sea level rise (Hallegatte et al., 2013).
2. Ecosystem-based adaptation: Restoring and protecting ecosystems, such as mangroves, coral reefs, and wetlands, can provide natural barriers against the impacts of climate change, such as coastal flooding and erosion, as well as provide additional ecosystem services and support biodiversity (Seddon et al., 2016).
3. Climate-resilient agriculture: Implementing agricultural practices that increase crop resilience to climate change, such as crop diversification, precision agriculture, and the use of drought-tolerant crop varieties, can help ensure food security in a changing climate (Howden et al., 2007).
4. Early warning systems and disaster risk reduction: Developing and implementing early warning systems for extreme weather events and natural disasters can help communities prepare for and respond more effectively to risks related to climate change, reducing the loss of life and property (Pulwarty & Sivakumar, 2014).

5. Public health interventions: Strengthening public health systems and implementing targeted interventions, such as controlling disease vectors and improving air quality, can help minimize the health impacts of climate change (Ebi & Semenza, 2008).

The continued impact of human activities on the global climate requires urgent action to mitigate greenhouse gas emissions and adapt to the consequences of climate change. By transitioning to renewable energy sources, improving energy efficiency, adopting sustainable soil management practices and implementing effective adaptation strategies, it is possible to address the challenges posed by climate change and safeguard the well-being of human and natural systems.

2.2 BIODIVERSITY

A. Definition and importance of biodiversity

Biodiversity, a term derived from the words "biological" and "diversity," refers to the variety and variability of life on Earth. It covers the entire spectrum of living organisms and the complex interactions between them, including their genetic diversity, the species they constitute, and the ecosystems they inhabit. This section will delve into the definition and importance of biodiversity, discussing its various dimensions and the vital role it plays in supporting ecosystem services and human well-being.

Biodiversity can be described at three fundamental levels: genetics, species and ecosystem diversity. Genetic diversity refers to the variation of genes within a species, which allows it to adapt to various environmental conditions and facilitates evolution. Species diversity, on the other hand, is the variety of species within an ecosystem, which is important for maintaining its stability and resilience. Finally, ecosystem diversity pertains to the variety of habitats, communities, and ecological processes within an area (Hooper et al., 2005).

Biodiversity plays a critical role in ensuring the stability and functioning of ecosystems, as well as in providing essential services to human societies (Cardinale et al., 2012). These ecosystem services can be categorized into four main types: provisioning, regulation, cultural and support services (Millennium Ecosystem Assessment, 2005). Supply services include the production of food, water, timber and other resources, while regulatory services cover climate regulation, flood control, water purification and pollination. Cultural services involve the aesthetic, recreational and spiritual values associated with ecosystems, and support services include nutrient cycling, soil formation and primary production

The importance of biodiversity for the functioning of ecosystems has been amply demonstrated through empirical research (Tilman et al., 2001; Loreau et al., 2001; Hooper et al., 2012). A meta-analysis conducted by Cardinale et al. (2012) found that biodiversity loss has negative consequences for ecosystem functioning and stability, with a decline in species richness resulting in reduced primary productivity, decomposition rates, and nutrient cycling. In addition, biodiversity plays a key role in promoting the resilience of ecosystems, allowing them to recover from disturbances and adapt to changing environmental conditions (Elmqvist et al., 2003).

Biodiversity also has direct and indirect benefits for human well-being. For example, many medications are derived from plants and other organisms, with more than 50% of the best-selling prescription drugs in the United States having their origins in natural products (Newman & Cragg, 2012). In addition, genetic diversity within agricultural crops and livestock breeds is vital for food security as it allows the development of new crop varieties and animal breeds resistant to diseases, pests and environmental stresses (Pimentel et al., 1997).

In addition to its practical implications, biodiversity has intrinsic value for many people, as it contributes to the aesthetic and cultural dimensions of human life. For example, natural landscapes, flora and fauna often serve as sources of inspiration for artists, writers, and philosophers, while the conservation of unique ecosystems and species is an important aspect of many indigenous cultures (Posey, 2000).

Despite its immense value, biodiversity is currently under threat from multiple human-induced factors, such as habitat destruction, climate change, pollution, overexploitation, and the introduction of invasive species (Butchart et al., 2010). These anthropogenic factors have led to unprecedented rates of species extinction (Pimm et al., 2014). The loss of biodiversity not only undermines the stability and functioning of ecosystems, but also compromises the provision of essential ecosystem services and the well-being of human societies (Cardinale et al., 2012; Díaz et al., 2019).

Given the importance of biodiversity for ecological and human well-being, there is an urgent need to develop and implement effective conservation strategies to protect it (Mace et al., 2018). Such strategies should be based on a comprehensive understanding of the complex interactions between the different dimensions of biodiversity, as well as the socioeconomic factors driving its decline (Mace et al., 2018). In addition, biodiversity conservation requires a collaborative and interdisciplinary approach, encompassing the input of ecologists, conservation biologists, social scientists, policymakers, and local communities (Cowling et al., 2008).

In short, biodiversity is a fundamental aspect of life on Earth, encompassing the genetic, species and ecosystem diversity that underpins the stability and functioning of ecosystems. Its importance extends beyond the ecological domain, providing essential ecosystem services that support human well-being, from the production of food and medicines to cultural and aesthetic values. However, the current global biodiversity crisis, driven by multiple anthropogenic factors, requires urgent and concerted efforts to conserve and restore biodiversity in order to safeguard ecological and human well-being for future generations.

3 MAIN THREATS TO BIODIVERSITY

Biodiversity, the variety of life on Earth, is essential to maintaining the health of ecosystems and providing vital goods and services to human society. However, biodiversity currently faces several threats, some of which are considered particularly critical. This section of the chapter aims to explore the main threats to biodiversity, with a focus on habitat loss and fragmentation, invasive species, pollution, climate change, and overexploitation.

B1. Habitat loss and fragmentation

Habitat loss is the main driver of biodiversity decline worldwide (Foley et al., 2005). As human populations expand, natural habitats are converted into farmland, urban areas, and infrastructure, leading to the destruction and fragmentation of ecosystems (Gibson et al., 2011). This process disrupts species distributions, population dynamics, and interactions, often resulting in local extinctions and reducing overall biodiversity. In particular, fragmentation is detrimental to the persistence of species with large ranges, low population densities, and specific habitat requirements (Ewers & Didham, 2006).

B2. Invasive species

Invasive species are non-native organisms that cause damage to the environment, the economy, or human health (Simberloff et al., 2013). They can outnumber native species by resources, alter ecosystem functions, and introduce diseases or parasites, resulting in the decline or extinction of native species (Clavero & García-Berthou, 2005). The spread of invasive species has been facilitated by human activities, including international trade, transportation, and habitat modification (Hulme, 2009). The impact of invasive species is particularly severe on islands, where native species have evolved in isolation and are often ill-equipped to compete or defend against invaders (Sax & Gaines, 2008).

An example of the destructive capacity of biodiversity by invasive species is the disease caused by a Bd fungus (Batrachochytrium dendrobatidis), also known as chytrid, which is primarily responsible for the greatest loss of biological diversity among amphibians worldwide. Contamination from this bottom has already extinguished dozens of amphibian species and, no doubt, many others not known to science. (Cheng et al, 2011)

B3. Pollution

Pollution is another significant threat to biodiversity, with various forms of pollution posing different risks to species and ecosystems. Chemical pollution, such as pesticides, heavy metals, and persistent organic pollutants, can contaminate terrestrial and aquatic habitats, leading to direct mortality, reduced reproductive success, and altered behavior in exposed organisms. Nutrient pollution, particularly from agricultural runoff, can cause eutrophication in aquatic ecosystems, resulting in algal blooms, oxygen depletion, and declining biodiversity. In addition, light and noise pollution can disrupt the behavior, communication, and reproductive success of species, particularly in nocturnal and acoustic species (Rosa, L., 2022).

B4. Climate change

Climate change poses a significant and growing threat to biodiversity as it alters temperature and precipitation patterns, which in turn affects species distributions, phenology, and interactions (Parmesan & Yohe, 2003). Many species are expected to shift their ranges to the pole or to higher altitudes in response to climate change, but the ability of species to track suitable habitats depends on their ability to disperse, the availability of suitable habitat, and the degree of human-induced landscape fragmentation (Thomas et al., 2004). In addition to changes in distribution, climate change can exacerbate other threats to biodiversity, such as habitat loss, invasive species, and disease (Brooks et al., 2002).

B5. Overexploitation

Overexploitation, the unsustainable harvesting of plants and animals for food, medicine, or other purposes, has historically been a major driver of species decline and extinction (Myers & Worm, 2003). Unsustainable hunting and fishing practices can lead to population collapse, with cascading effects on food webs and ecosystem functioning. In addition, selective harvesting of certain species or individuals can alter population genetics and disrupt ecological processes such as pollination and seed dispersal (Keller et al., 2011). Overexploitation is particularly problematic in developing countries and regions with weak governance, where illegal and unregulated harvesting may persist despite conservation efforts (Brashares et al., 2004).

In summary, habitat loss and fragmentation, invasive species, pollution, climate change and over-exploitation are the main threats to biodiversity. These threats are interconnected and often act synergistically, making their cumulative impact on biodiversity even greater (Brook et al., 2008). Addressing these threats requires coordinated global action, such as habitat restoration and protection, invasive species management, pollution reduction, climate change mitigation and adaptation, and sustainable resource use (Butchart et al., 2010). Ongoing research is essential to understand the complex interactions between these threats and identify effective conservation strategies to safeguard global biodiversity.

4 RELATIONSHIP BETWEEN BIODIVERSITY AND ECOSYSTEM RESILIENCE

Biodiversity and ecosystem resilience are interconnected concepts in ecology, with mutual influence. Biodiversity refers to the variety of life in a given ecosystem or across the Earth, encompassing genetic, species, and ecosystem levels (Mace et al., 2012). Ecosystem resilience refers to the ability of an ecosystem to recover from disturbances and return to its original state. This section aims to review the relationship between biodiversity and ecosystem resilience, highlighting empirical evidence and theoretical underpinnings, as well as discussing the implications for conservation efforts.

C1. Biodiversity and ecosystem resilience: empirical evidence

In the context of global environmental change, the resilience of ecosystems becomes critical for the long-term survival of species and for the consistent delivery of ecosystem services. Evidence has shown that biodiversity at all levels contributes significantly to ecosystem resilience. Understanding this phenomenon has important practical implications. Despite some gaps in scientific knowledge, a substantial amount of reliable empirical evidence from different types of ecosystems at different spatial and temporal scales supports the fact that biodiversity contributes significantly to ecosystem resilience. This is particularly important in the context of global environmental change. It was also found that biodiversity mechanisms that contribute to ecosystem resilience at all levels are interconnected. This has important practical implications, requiring a holistic approach to biodiversity conservation to ensure ecosystem resilience rather than focusing on the conservation of selected species (Vasiliev, 2022).

Several studies have shown a positive relationship between biodiversity and ecosystem resilience, indicating that more diverse ecosystems are better equipped to withstand and recover from disturbances. In addition, it was observed that higher species diversity led to increased drought resistance in experimental grassland ecosystems (Oliver et al., 2015). Similarly, Isbell et al. (2015) found that several fields recovered more quickly from drought, supporting the hypothesis that biodiversity increases the resilience of ecosystems.

The relationship between biodiversity and ecosystem resilience has also been demonstrated in aquatic systems. Cardinale et al (2012) conducted a meta-analysis of 64 experimental studies and found that greater species diversity in aquatic environments improved ecosystem functions such as primary production, nutrient cycling, and decomposition, thereby increasing its resilience.

c2. Biodiversity and ecosystem resilience: theoretical foundations

Several theories have been proposed to explain the relationship between biodiversity and ecosystem resilience. One of the most prominent is the "insurance hypothesis," which posits that high levels of biodiversity provide a "buffer" against environmental fluctuations and disturbances. According to this theory, a diverse community of species can maintain ecosystem functioning during disturbances, as some species may be more resistant to disturbance or better capable of rapid recovery (Folke et al., 2004; Yachi & Loreau, 1999)

The "redundancy hypothesis" is another theory that attempts to explain the relationship between biodiversity and ecosystem resilience. This hypothesis suggests that the presence of multiple functionally similar species (i.e., redundant species) within an ecosystem may increase its resilience to disturbances (Walker, 1992). When a disturbance occurs, functionally redundant species can compensate for the loss of other species, thereby maintaining ecosystem function and stability.

c3. Implications for conservation

Understanding the relationship between biodiversity and ecosystem resilience has significant implications for conservation efforts. As ecosystems around the world face increasing pressures from human activities and climate change, it is crucial to maintain and restore biodiversity to increase the resilience of these ecosystems. By preserving biodiversity, conservation efforts can help ensure the continued provision of vital ecosystem services, such as water purification, carbon sequestration, and pollination, that are essential for human well-being (Millennium Ecosystem Assessment, 2005).

The relationship between biodiversity and ecosystem resilience is a critical area of study in ecology. Empirical evidence and theoretical frameworks suggest that higher levels of biodiversity increase the resilience of ecosystems, allowing ecosystems to better resist and recover from disturbances. The insurance hypothesis and the redundancy hypothesis are two key theories that explain this relationship. These theories suggest that diverse ecosystems are more stable and better able to maintain their functioning in the face of environmental fluctuations and disturbances, due to the presence of functionally diverse and redundant species.

Conservation efforts must prioritize maintaining and increasing biodiversity to ensure the resilience of ecosystems in the face of ongoing environmental challenges such as climate change and habitat loss. In doing so, these efforts can help safeguard the vital ecosystem services on which human societies depend. To this end, conservation strategies must be guided by a comprehensive understanding of the complex relationship between biodiversity and ecosystem resilience, taking into account the underlying mechanisms and context-specific nature of these relationships (Elmqvist et al., 2003).

The relationship between biodiversity and ecosystem resilience is important for understanding ecosystem dynamics and informing effective conservation strategies. As global environmental pressures continue to increase, it is increasingly important to prioritize the preservation of biodiversity to increase the resilience of ecosystems and ensure the continued provision of essential ecosystem services.

4.1 IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Climate change has emerged as a major threat to global biodiversity, with the potential to drive extinctions, disrupt ecosystems, and alter the distribution and abundance of species (Parmesan, 2006; Thomas et al., 2004). Rapid changes in climatic conditions directly affect the distribution, abundance, and interactions of species, while indirectly influencing ecosystem structure and functions. Consequently, these changes can lead to the loss of genetic diversity within populations, decreasing their resilience to environmental disturbances. This section of the chapter aims to synthesize the current understanding of the impact of climate change on biodiversity, focusing on key areas such as changes in species distribution, phenological changes, and the relationship between climate change, extinction risk, and reduced genetic diversity.

A. Habitat changes and species distribution

One of the most visible impacts of climate change on biodiversity is the alteration of the geographical distribution of species (Parmesan and Yohe, 2003). As temperatures rise, species are forced to shift their distributions to the pole or to higher altitudes in order to maintain their ideal climatic conditions (Chen et al., 2011). These distribution changes can lead to new species groupings, with potential consequences for ecosystem functioning (Walther et al., 2002).

A meta-analysis by Parmesan and Yohe (2003) found that 279 species had shifted their ranges to the pole by an average of 6.1 km per decade, and that these changes were consistent with the expected response to climate change. This result highlights the profound effects of climate change on the distribution of species and highlights the importance of monitoring and conserving suitable habitats for species at risk.

B. Phenological changes

Another significant impact of climate change on biodiversity is the alteration of species phenology, or the timing of seasonal events (Parmesan & Yohe, 2003; Raiz et al., 2003). Phenology deals with biological events in relation to seasonal and climatic changes. Phenological incompatibilities, due to changes in the timing of biological events such as flowering, migration, or reproduction, can also result from climate change. These incompatibilities can disrupt interactions between species, such as predator-prey dynamics or the plant-pollinator relationship, leading to declines in population size and increased extinction risks (Parmesan and Hanley, 2015). For example, changes in the timing of bird migration due to climate change have led to mismatches between the availability of food resources and the arrival of migratory birds, negatively impacting their reproductive success (Both et al., 2010).

Changes in phenology can have cascading effects on ecosystems, as interactions between species can be disrupted when events such as migration, flowering, or reproduction occur at different times (Visser & Both, 2005). For example, incompatibilities have been observed in the time of food availability and in the reproduction of migratory birds (Both et al., 2006), which could lead to population declines and reduced reproductive success.

Root et al (2003) reported that 62% of the species examined showed significant changes in phenology, and most of these changes occurred at the beginning of the year. This is consistent with the findings of Parmesan (2007), who reported that spring events such as flowering and insect emergence were occurring earlier due to climate change. The potential consequences of these phenological changes on ecosystem functioning and interactions between species deserve further investigation.

C. Risk of extinction and climate change

The relationship between climate change and the risk of species extinction is complex, as multiple factors interact to determine a species' vulnerability to extinction (Brook et al., 2008). Climate change can exacerbate existing threats to species, such as habitat loss and fragmentation, overexploitation and the spread of invasive species (Bellard et al., 2012). In addition, some species may be more vulnerable to the effects of climate change due to their specific ecological needs, life history characteristics, or limited dispersal abilities (Foden et al., 2013).

Habitat loss as a result of climate change has been documented in diverse ecosystems, leading to the decline and potential extinction of numerous species (Urban, 2015). For example, rising temperatures and changes in precipitation patterns have caused the loss of suitable habitats for several species, particularly those with limited dispersal capacities or narrow ecological niches (Warren et al., 2018).

Range changes represent another critical mechanism through which climate change can contribute to species extinction. As species seek suitable climatic conditions, their distributions may shift to higher latitudes or altitudes. However, not all species possess the ability to adapt to new environments or successfully disperse to suitable habitats. Consequently, these species may experience contractions in their geographic distribution, population declines, and ultimately an increased risk of extinction (Wolf & Ripple, 2017).

Thomas et. al(2004) estimated that 15-37% of species could be "committed to extinction" by 2050 due to climate change, based on a range of climate change scenarios and the species' sensitivity to climate change. However, this estimate has been widely debated, with some arguing that it may be an overestimate (Botkin et al., 2007) or an underestimation (Urban, 2015) of the true extinction risk. Regardless of the precise estimate, the potential of climate change to contribute to species extinction is a cause for concern and highlights the need for effective conservation strategies to mitigate these impacts.

C1. Strategies for mitigating the impacts of climate change on biodiversity

Addressing the impacts of climate change on biodiversity requires a combination of mitigation and adaptation strategies. Mitigation efforts aim to reduce greenhouse gas emissions and limit the extent of climate change (IPCC, 2014). However, given the inevitability of some degree of climate change, adaptation strategies must also be implemented to minimize impacts on biodiversity (Heller and Zavaleta, 2009).

Adaptation strategies include increasing habitat connectivity to facilitate changes in species distribution (Heller & Zavaleta, 2009), the conservation and restoration of ecosystems that provide important services such as carbon sequestration and climate regulation (Bullock et al., 2011), and the implementation of assisted migration or translocation for species at high risk of extinction (Hoegh-Guldberg et al., 2008). In addition, integrating climate change considerations into existing conservation planning and decision-making frameworks is essential to ensure that biodiversity conservation efforts are effective in the face of climate change (Hannah et al., 2002).

The impacts of climate change on biodiversity are complex and far-reaching, affecting species distribution, phenology and extinction risk. These impacts have the potential to disrupt ecosystems and threaten the provision of ecosystem services essential to human well-being. Mitigation and adaptation to these impacts is critical to the conservation of global biodiversity and the maintenance of ecosystem services. Ongoing research is needed to improve understanding of the complex interactions between climate change and biodiversity, and to inform conservation strategies.

D. Extinction of species and reduction of genetic diversity

Climate change can lead to reduced genetic diversity within populations through various processes, including population bottlenecks, selection pressures, and disruptions in gene flow. Population bottlenecks, characterized by drastic reductions in population size, can be induced by extreme weather events or habitat loss, resulting in the loss of genetic diversity. Because genetic diversity is critical to the adaptive potential of populations, these bottlenecks can exacerbate species' susceptibility to environmental stressors and increase their risk of extinction (Hoffmann and Sgrò, 2011).

Selection pressures induced by climate change can also lead to reduced genetic diversity within populations. For example, rapid changes in environmental conditions can impose strong selection on specific traits, favoring individuals with greater fitness under the new conditions (Bellard et al., 2012). While this may increase the adaptability of populations to climate change, it may also result in the loss of genetic variation to traits that may be beneficial in the face of future environmental disturbances (Valladares et al., 2014).

In addition, disruptions in gene flow due to climate change may contribute to the reduction of genetic diversity. Changes in climatic conditions can lead to habitat fragmentation or the formation of barriers, preventing the movement of individuals and the exchange of genetic material between populations. This reduced gene flow can result in the isolation of populations, further decreasing their genetic diversity and increasing their vulnerability to local extinction (Foden et al., 2013).

D1. Implications for conservation

The ongoing impacts of climate change on species extinction and reduced genetic diversity have significant implications for biodiversity conservation. Strategies to mitigate these consequences include the establishment of protected areas, habitat restoration, assisted migration, and the maintenance of genetic diversity within populations. Protected areas can cushion species against climate change by providing suitable habitats and facilitating connectivity between populations (Hannah et al., 2020). Habitat restoration, on the other hand, can increase the resilience of ecosystems by promoting the recovery of native species and restoring ecosystem functions (Rey Benayas et al., 2017).

Assisted migration, which involves the translocation of species to suitable habitats outside their historical ranges, has been proposed as a potential solution to combat the effects of climate change on species distribution (McLachlan et al., 2017). However, this approach is not without risks, as it can lead to the introduction of invasive species or the disruption of local ecosystems (Ricciardi and Simberloff, 2009). Therefore, assisted migration should be carefully considered and implemented only when the benefits outweigh the potential risks (Hewitt et al., 2011).

Finally, maintaining genetic diversity within populations is crucial to increasing their adaptive potential and resilience to climate change. Conservation efforts should focus on preserving habitat connectivity, managing gene flow between populations, and promoting the persistence of diverse genetic lineages (Frankham, 2010).

The impact of climate change on species extinction and reduced genetic diversity poses a significant threat to global biodiversity. Understanding these complex interactions and their consequences is essential for developing effective conservation strategies to mitigate the impacts of climate change on ecosystems and preserve the Earth's biodiversity for future generations. This section of the scientific article provided a review of the literature on the topic, examining various mechanisms of species extinction and loss of genetic diversity, as well as discussing the implications of these phenomena for conservation.

5 METHODOLOGY

In this study, the option was a twofold methodological approach: systematic review and analysis of secondary data. This approach was chosen to ensure a comprehensive and rigorous understanding of the challenges and opportunities that biodiversity conservation faces in the face of climate change.

The systematic review was used to identify, evaluate and interpret available and relevant research on the subject. The systematic review method was chosen because it is an effective tool to assess the large amount of existing literature on ecological resilience and climate change. Its rigorous and replicable approach helps to minimize bias and allow for a more accurate and comprehensive assessment of the current state of knowledge on the topic.

The systematic review was performed following the following steps: definition of inclusion and exclusion criteria, literature search, study selection, data extraction and evaluation of the quality of the studies. The databases consulted included, but were not limited to, PubMed, Web of Science, Scopus, JSTOR and Google Scholar. The keywords used in the search were, mainly, "ecological resilience", "climate change", "biodiversity conservation", among others relevant to the theme.

The second component of the methodology used, secondary data analysis, was used to assess the impact of climate change on biodiversity on a broader scale. This method was chosen because secondary data is a valuable source of information that has already been collected and validated, making it possible to reach globally without the cost and time associated with primary data collection.

Secondary data were obtained from a variety of sources, including reports from governmental and non-governmental organizations, climate and biodiversity databases such as the World Database on Protected Areas (WDPA), the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), and the Intergovernmental Panel on Climate Change (IPCC). These data were analyzed to identify patterns and trends in the relationship between climate change and biodiversity.

Combining the systematic review with the analysis of secondary data, the expectation was to gain a comprehensive understanding of the challenges and opportunities that biodiversity conservation faces in the context of climate change. This approach will allow us to identify areas where more research is needed and provide recommendations for the formulation of conservation and ecosystem management policies.

6 RESULTS AND DISCUSSION

6.1 EFFECTS OF CLIMATE CHANGE ON BIODIVERSITY GLOBALLY

Climate change has become one of the most pressing issues facing the planet. Its effects on biodiversity are widespread, impacting various biomes and species around the world (Bellard et al., 2012). This section of the chapter will explore the examples of impacts on different biomes and species and the observed trends and predictions for the future.

A. Examples of impacts on different biomes and species

Climate change has been shown to affect different biomes and species in myriad ways. Some of the impacts observed include changes in distribution ranges, altered phenology, and potential for local extinctions (Parmesan, 2006). These changes have significant consequences for ecosystem processes, affecting species interactions and ecosystem services.

Terrestrial ecosystems, such as tropical forests and boreal forests, are particularly susceptible to climate change. For example, rising temperatures and changing rainfall patterns have been associated with increased tree mortality and reduced species richness in tropical forests (Feeley et al., 2012). Similarly, boreal forests are experiencing changes in species composition and distribution due to climate-induced changes in fire regimes and insect outbreaks (Johnstone et al., 2010).

In aquatic ecosystems, climate change has led to changes in the distribution and abundance of marine and freshwater species. Ocean warming and acidification are causing changes in species distribution, with many species moving to higher latitudes or deeper waters (Poloczanska et al., 2013). In addition, changes in river flow regimes are altering the distribution and abundance of freshwater species, potentially leading to localized extinctions (Xenopoulos et al., 2005).

The Arctic and Alpine biomes are among the most vulnerable to climate change due to their sensitivity to temperature fluctuations and reduced habitat availability. For example, the decline of Arctic sea ice has serious implications for ice-dependent species such as polar bears and seals (Laidre et al., 2008). Similarly, alpine plant species are at risk due to upward changes in their distributions and increased competition from lowland invasive species (Gottfried et al., 2012).

B. Observed trends and predictions for the future

As climate change progresses, current trends of biodiversity loss are expected to intensify. According to Strona and Bradshaw (2022) simulations predict a dramatic loss of diversity by the end of the century. Depending on the climate change scenario, by 2050 local ecosystems will have lost on average between 6% and 10.8% of their vertebrate species. By 2100, this increases to an average loss of diversity of 13-27%. They also observed a faster decline in diversity between 2020 and 2050 than afterward. This suggests that the coming decades will be decisive for the future of global biodiversity. In addition, species distribution models suggest that climate change will lead to a significant reduction in the size of the geographic distribution of many species (Warren et al., 2013).

Changes in phenology, or the timing of seasonal events such as flowering and migration, are expected to continue as a result of climate change. These changes can lead to incompatibilities between species and their resources, affecting interactions between species and ecological processes (Thackeray et al., 2010). For example, earlier arrival of migratory birds has been associated with reduced reproductive success due to incompatibilities with their food sources (Both et al., 2006).

In the future, climate change is also expected to exacerbate existing threats to biodiversity, such as habitat fragmentation and invasive species. For example, climate change can facilitate the spread of invasive species, creating more suitable conditions for their establishment and growth (Walther et al., 2009). In addition, altered precipitation patterns and increased frequency of extreme weather events can lead to habitat loss and degradation, reducing the resilience of ecosystems to climate change (Foden et al., 2013).

The fact is that climate change poses significant threats to global biodiversity, impacting various biomes and species in myriad ways. Current trends and predictions for the future indicate that these impacts are likely to intensify, with potentially catastrophic consequences for ecosystem processes, interactions between species, and the provision of ecosystem services. It is critical that researchers and policy makers continue to investigate and monitor the effects of climate change on biodiversity in order to develop effective mitigation and adaptation strategies. Ultimately, efforts to address climate change and protect biodiversity must be integrated to ensure the long-term sustainability of the planet's ecosystems and the countless species that inhabit it.

6.2 CONSERVATION AND ADAPTATION STRATEGIES

The conservation of biological diversity and the implementation of adaptation strategies have gained increasing attention in the face of global climate change and biodiversity loss (IPCC, 2014; CBD, 2010). This section of the chapter explores the various conservation and adaptation measures and strategies, including in situ and ex situ conservation, ecological restoration and corridors, and international policies and agreements.

A. In situ and ex situ conservation measures

In situ conservation, which involves the preservation of species in their natural habitats, is considered the most effective strategy for biodiversity conservation (Primack, 2014; Hunter and Gibbs, 2006). Protected areas, such as national parks and wildlife reserves, serve as the primary method for in situ conservation, providing refuge for endangered species and ecosystems (Gaston et al., 2006). The effectiveness of protected areas depends on proper management, adequate funding, and the involvement of local communities in decision-making processes (Watson et al., 2014).

However, in situ conservation alone is not sufficient to address the challenges posed by climate change and anthropogenic pressures (Bottrill et al, 2008; Hannah et al(2002). Ex situ conservation, which involves keeping species out of their natural habitats, has emerged as a complementary approach to in situ conservation (Hamilton & Hamilton, 2006). Ex situ techniques include captive breeding, seed banks, and botanical gardens, providing a "genetic insurance policy" for endangered species (Guerrant et al., 2004). The integration of in situ and ex situ conservation strategies allows for a more comprehensive approach to biodiversity conservation and the preservation of genetic diversity (Volis, 2016).

B. Ecological restoration and ecological corridors

Ecological restoration aims to rehabilitate degraded ecosystems and promote the recovery of their ecological functions. This approach contributes to biodiversity conservation by restoring habitats and supporting species persistence (Hobbs et al., 2004). For example, restoring wetlands can increase carbon sequestration, mitigating the impacts of climate change and preserving biodiversity (Mitsch et al., 2013).

The establishment of ecological corridors is another important strategy for biodiversity conservation and adaptation to climate change. Ecological corridors, which are continuous or interconnected habitats, facilitate the movement and migration of species, promoting genetic exchange and increasing the resilience of species to environmental changes (Heller and Zavaleta, 2009). Corridors can be particularly beneficial for species with limited dispersal abilities or specific habitat requirements, as they allow populations to access suitable habitats in the face of climate change-induced changes (Lawler et al., 2009).

C. International policies and agreements to combat climate change and protect biodiversity

International cooperation is essential for the effective conservation of biodiversity and the implementation of adaptation strategies in the face of global challenges. The Convention on Biological Diversity (CBD) is an important international agreement that aims to promote the conservation of biodiversity, the sustainable use of its components and the equitable sharing of the benefits derived from genetic resources (CBD, 2010). The CBD Strategic Plan for Biodiversity 2011-2020, including the Aichi Biodiversity Targets, provided a global framework for action to address the factors underlying biodiversity loss (Tittensor et al., 2014).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is another important international initiative that aims to strengthen the science-policy interface for biodiversity conservation and sustainable development (Díaz et al., 2015). IPBES assessments, which synthesize scientific knowledge about the state of biodiversity and ecosystem services, provide evidence-based policy recommendations for decision-makers at various levels (Díaz et al., 2015).

The Paris Agreement, adopted under the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, represents a milestone in the global effort to combat climate change and adapt to its impacts (UNFCCC, 2015). The Agreement aims to limit global temperature rise to well under 2°C above pre-industrial levels, emphasizing the need for adaptation measures and financial support to developing countries (UNFCCC, 2015). By addressing the impacts of climate change, the

Paris Agreement contributes indirectly to biodiversity conservation by promoting the resilience of ecosystems and species to environmental change.

Biodiversity conservation and the implementation of adaptation strategies are essential in the face of global climate change and biodiversity loss. In situ and ex situ conservation measures, ecological restoration and ecological corridors represent fundamental strategies for the preservation of species and ecosystems. International policies and agreements, such as the CBD, IPBES and the Paris Agreement, provide a framework for global cooperation and action to protect biodiversity and address the challenges posed by climate change. Integrating these strategies and strengthening international collaboration are key to ensuring long-term biodiversity conservation and ecosystem resilience.

7 CONCLUSION

The chapter presented a comprehensive examination of the complex interplay between climate change and its impacts on biodiversity. The conclusions can be summarized in three approaches:

7.1 SUMMARY OF THE MAIN RESULTS OBTAINED

A. Climate change poses significant threats to biodiversity through a combination of direct and indirect effects, such as rising temperatures, ocean acidification, habitat loss, changes in species distribution, and changes in phenology and interactions between species. These factors have already led to the decline of countless species and could result in mass extinctions in the future.

B. The chapter highlights the importance of ecosystem resilience in the face of climate change, emphasizing the role of intact ecosystems in providing crucial ecosystem services and cushioning the adverse effects of climate change.

C. It is evident that the vulnerability of species and ecosystems to climate change varies greatly, with some species being more resilient and adaptive, while others are more susceptible to extinction due to limited adaptive capacities and high sensitivity to environmental changes.

7.2 THE PRACTICAL AND POLICY IMPLICATIONS FOR BIODIVERSITY CONSERVATION BASED ON THE RESULTS OF THIS STUDY ARE

A. The need for immediate and effective climate change mitigation strategies to limit global temperature rise and reduce the impacts associated with biodiversity. This includes transitioning to renewable energy sources, reducing greenhouse gas emissions, and promoting sustainable land-use practices.

B. The implementation of adaptive management approaches in conservation planning to account for the uncertainties and complexities associated with climate change. This includes incorporating climate change projections into conservation decision-making processes and prioritizing the protection of climate-resilient habitats and species.

C. Increase the resilience of ecosystems through the restoration of degraded ecosystems, the establishment of ecological corridors to facilitate the movement of species and the promotion of biodiversity in agricultural landscapes to support the functioning of ecosystems.

D. Promote international cooperation and coordinated efforts to address the global challenge of climate change and biodiversity loss, including the sharing of data, resources and knowledge, as well as the establishment of collaborative research initiatives and policy frameworks.

7.3 SUGGESTIONS FOR FUTURE RESEARCH AND ACTION

A. Further studies on the complex interactions between climate change and biodiversity, including the development of predictive models to better understand potential impacts on species and ecosystems, and to identify vulnerable areas and species of concern.

B. Increased monitoring and data collection on the impacts of climate change on biodiversity to improve our understanding of the rates, scales and patterns of change and inform adaptive management strategies.

C. Research on the effectiveness of different conservation strategies and interventions in mitigating the impacts of climate change on biodiversity, to guide decision-making and policy development.

D. Research into the potential of assisted migration, genetic rescue and other new conservation approaches to facilitate the adaptation and survival of species in the face of climate change.

By addressing these research and action priorities, it is possible to work collectively to better understand and manage the impacts of climate change on biodiversity and ensure the long-term survival of ecosystems and the services they provide to human societies.

REFERENCES

Anenberg, S. C., Horowitz, L. W., Tong, D. Q., & West, J. J. (2010). An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. Environmental Health Perspectives, 118(9), 1189–1195.

Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D., & Houghton, R. A. (2017). Tropical forests are a net source of carbon based on above-ground measurements of gain and loss. Science, 358(6360), 230–234.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. Ecology Letters, 15(4), 365-377.

Both, C., Bouwhuis, S., Lessells, C. M., & Visser, M. E. (2006). Climate change and population declines in a long-distance migratory bird. Nature, 441(7089), 81-83.

Both, C., Van Turnhout, C. A., Bijlsma, R. G., et al (2010). Avian population consequences of climate change are most severe for long-distance migrants in seasonal habitats. Proceedings of the Royal Society B: Biological Sciences, 277(1685), 1259-1266.

Botkin, D. B., Saxe, H., Araújo, M. B., et al (2007). Forecasting the effects of global warming on biodiversity. BioScience, 57(3), 227-236.

Bottrill, M.C., et al. (2008). "Is conservation triage just smart decision making?" Trends in Ecology & Evolution, 23(12), 649-654.

Brashares, J. S., Arcese, P., Sam, M. K., Coppolillo, P. B., Sinclair, A. R. E., d. Balmford, A. (2004). Bushmeat hunting, wildlife declines and fish supply in West Africa. Science, 306(5699), 1180-1183.
Brook, B. W., Sodhi, N. S., Bradshaw, C. J. A. (2008). Synergies between the factors of extinction under global change. Trends in Ecology and Evolution, 23(8), 453-460.

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G. et al. (2002). Habitat loss and extinction in biodiversity hotspots. Conservation Biology, 16(4), 909-923

Bullock, J. M., Aronson, J., Newton, A. C., et al (2011). Restoration of ecosystem services and biodiversity: conflicts and opportunities. Trends in Ecology & Evolution, 26(10), 541-549.

Butchart, S. H. M., Walpole, M., Collen, B. et al(2010). Global biodiversity: Indicators of recent declines. Science, 328(5982), 1164-1168.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., et al (2012). Loss of biodiversity and its impact on humanity. Nature, 486(7401), 59–67.

CBD (2010). Strategic Plan for Biodiversity 2011-2020. Convention on Biological Diversity. Disponível em: https://www.cbd.int/sp/

Chen, I. C., Hill, J. K., Ohlemüller, R., Roy, D. B., & Thomas, C. D. (2011). Rapid range shifts of species associated with high levels of climate warming. Science, 333(6045), 1024-1026.

Cheng, T.L., Rovito, S.M., Wake, D.B. and Vredenburg, V.T. (2011) Coincident mass extirpation of neotropical amphibians with the emergence of the infectious fungal pathogen Batrachochytrium dendrobatidis. Proceedings of the National Academy of Sciences, 108(23), 9502–9507.

Church, J. A., White & N. J. (2011). Sea level rise from the late 19th century to the early 21st century. Surveys in Geophysics, 32(4-5), 585-602. https://doi.org/10.1007/s10712-011-9119-1

Clavero, M., & García-Berthou 2005). Invasive species are one of the main causes of animal extinction. Trends in Ecology and Evolution, 20(3), p.110.

Cowling,R.M., Egoh, Benis, Knight, Andrew, O'Farrell, Patrick, et al. (2008). An operational model for mainstreaming ecosystem services for implementation. Proceedings of the National Academy of Sciences of the United States of America. 105. 9483-9488. https://doi.org/10.1073/pnas.0706559105
Dias, R. (2015). Sustentabilidade: origem e fundamentos. São Paulo: Atlas, 248 p.

Díaz, S., et al. (2015). The IPBES Conceptual Framework — connecting nature and people. Current Opinion in Environmental Sustainability, 14, 1-16.

Díaz, S., et al. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. Science, 366(6471).

Ebi, K. L., Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. American Journal of Preventive Medicine, 35(5), 501–507.

EIA (2020). International Energy Statistics. U.S. Energy Information Administration. Disponível em: https:// https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf

Elmqvist, T., et al. (2003). Response diversity, ecosystem change, and resilience. Frontiers in Ecology and the Environment, 1(9), 488-494.

Ewers, R. M., Didham, R. K. (2006). Confounding factors in the detection of species responses to habitat fragmentation. Biological reviews of the Cambridge Philosophical Society,, 81(1), 117-142.

Feeley, K. J., Malhi, Y., Zelazowski, P., & Silman, M. R. (2012). The relative importance of deforestation, precipitation change, and temperature sensitivity in determining the future distributions and diversity of Amazonian plant species. Global Change Biology, 18(8), 2636-2647.

Foden, W. B., Butchart, S. H., Stuart, S. N., et al (2013). Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals. PLoS ONE, 8(6), e65427.

Foley, J. A., DeFries, R., Asner, G. P., et al (2005). Global consequences of land use. Science, 309(5734), 570-574.

Folke, C., Carpenter, S., Walker, B., et al (2004). Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics, 35, 557–581.

Frankham, R. (2010). Challenges and opportunities of genetic approaches to biological conservation. Biological Conservation, 143(9), 1919-1927.

Gaston, K.J., et al. (2006). The ecological effectiveness of protected areas: The United Kingdom. Biological Conservation, 132(1), 76-87.

Gerber, P. J., Steinfeld, H., Henderson, B., et al (2013). Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO).Rome.

Gibson, L., Lee, T. M., Koh, L. P. et al(2011). Primary forests are irreplaceable to sustain tropical biodiversity. Nature, 478(7369), 378-381.

Gottfried, M., Pauli, H., Futschik, A., et al (2012). Continent-wide response of mountain vegetation to climate change. Nature Climate Change, 2(2), 111-115.

Guerrant, Edward & Havens, Kayri & Maunder, Michael & Raven, Peter. (2004). Ex Situ Plant Conservation: Supporting Species Survival In The Wild. Island Press, Washington, D.C.

Hallegatte, S., Green, C., Nicholls, R. J., Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. Nature's Climate Change, 3(9), 802–806.

Hamilton,A. & Hamilton,P. (2006) Plant Conservation: An Ecosystem Approach, London, UK, 352 pp

Hannah, L., et al. (2002). Conservation of biodiversity in a changing climate. Conservation Biology, 16(1), 264-268.

Hannah, L., Midgley, G., Millar, D. (2002). Climate change-integrated conservation strategies. Global Ecology and Biogeography, 11(6), 485-495.

Hannah, L., Roehrdanz, P. R., Marquet, P. A., et al (2020). 30% land conservation and climate action reduces tropical extinction risk by more than 50%. Ecography, 43(7), 943-953.

Heller, N. E., & Zavaleta, E. S. (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation, 142(1), 14-32.

Hewitt, N., Klenk, N., Smith, A. L., et al (2011). Taking stock of the assisted migration debate. Biological Conservation, 144(11), 2560-2572.

Hinkel, J., Lincke, D., Vafeidis, A. T., et al (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. Proceedings of the National Academy of Sciences, 111(9), 3292–3297. https://doi:10.1073/pnas.1222469111

Hobbs, R.J., et al. (2004). Restoration ecology: the challenge of social values and expectations. Frontiers in Ecology and the Environment, 2(1), 43-48.

Hoegh-Guldberg, O., Hughes, L., McIntyre, S., (2008). Assisted colonization and rapid climate change. Science, 321(5887), 345-346.

Hoffmann, A. A., & Sgrò, C. M. (2011). Climate change and evolutionary adaptation. Nature, 470, 479-485.

Hooper, D. U., et al. (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs, 75(1), 3-35.

Hooper, D., Adair, E., Cardinale, B. et al. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature 486, 105–108 (2012). https://doi.org/10.1038/nature11118

Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., K. Maskell, and Johnson, C. A. (Eds.). (2001). Climate change 2001: The scientific basis. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA, 881pp.

Howden, S. M., Soussana, J. F., Tubiello, F. N., et al (2007). Adapting agriculture to climate change. Proceedings of the National Academy of Sciences, 104(50), 19691–19696.

Hulme, P. E. (2009). Trade, transport and problems: managing invasive species pathways in an era of globalisation. Journal of Applied Ecology, 46(1), 10-18.

Hunter, M.L., Gibbs,J. P. (2006). Fundamentals of Conservation Biology(Third edition). Blackwell Publishers.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland. 151 pgs.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

IPCC. (2013). Climate Change 2013: The Basis of Physical Science. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
IPCC. (2014). Climate Change 2014: Climate Change Mitigation. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C.Minx (eds.). Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC. (2019). Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Flows in Terrestrial Ecosystems. P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte,H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold,J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)Intergovernmental Panel on Climate Change. Disponível em: https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf

IPCC. (2021). Climate change 2021: The basis of physical science. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (eds.)]. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA, 2391 pp. https://doi:10.1017/9781009157896

Isbell, F., Craven, D., Connolly, J., et al (2015). Biodiversity increases the resistance of ecosystem productivity to climate extremes. Nature, 526(7574), 574–577.

Jacobson, M. Z., Delucchi, M. A., Bauer, Z. A., et al (2017). 100% clean and renewable wind, water and solar energy roadmaps for all sectors for 139 countries around the world. Joule, 1(1), 108–121.

Johnstone, J. F., Chapin III, F. S., Hollingsworth, T. N., Mack, M. C., Romanovsky, V., & Turetsky, M. (2010). Fire, climate change, and forest resilience in interior Alaska. Canadian Journal of Forest Research, 40(7), 1302-1312.

Keller, R. P., Geist, J., Jeschke, J. M., Kühn, I. (2011). Invasive species in Europe: ecology, status and policy. Environmental Sciences Europe, 23(23), pp.1-17

Laidre, K. L., Stirling, I., Lowry, L. F., et al (2008). Quantifying the sensitivity of Arctic marine mammals to climate-induced habitat change. Ecological Applications, 18(sp2), S97-S125.

Lawler, J.J., et al. (2009). Projected climate-induced faunal change in the Western Hemisphere. Ecology, 90(3), pp.588-597

Le Quéré, C., Jackson, R. B., Jones, M. W., et al (2020). Temporary reduction of daily global CO2 emissions during the forced lockdown of COVID-19. Nature Climate Change, 10(7), 647–653.

Lean, J. (2000). Evolution of the Sun's spectral irradiance since the Maunder Minimum. Geophysical Research Letters, 27(16), 2425-2428. https://doi.org/10.1029/2000GL000043

Loreau, M., et al. (2001). Biodiversity and ecosystem functioning: current knowledge and future challenges. Science, 294(5543), 804-808. https://doi: 10.1126/science.1064088

Lüthi, D., Le Floch, M., Bereiter, B., et al (2008). High resolution carbon dioxide concentration record 650,000-800,000 years before the present. Nature, 453(7193), 379–382.

Mace, G. M., Norris, K., & Fitter, A. H. (2012). Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology & Evolution, 27(1), 19–26.

Mace, G.M., Barrett, M., Burgess, N.D. et al. (2018) Aiming higher to bend the curve of biodiversity loss. Nature Sustainability 1, 448–451. https://doi.org/10.1038/s41893-018-0130-0

McLachlan, J. S., Hellmann, J. J., & Schwartz, M. W. (2007). A framework for debate of assisted migration in an era of climate change. Conservation Biology, 21(2), 297-302.

Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Synthesis. Island Press, Washington, DC.

Mitsch, W.J., et al. (2013). Wetlands, carbon, and climate change. Landscape Ecology, 28(4), 583-597. https://doi.org/10.1007/s10980-012-9758-8

Mora, C., Spirandelli, D., Franklin, E. C., et al (2018). Broad threat to humanity from cumulative climate hazard intensified by greenhouse gas emissions. Nature Climate Change, 8(12), 1062–1071.

Myers, R. A., Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. Nature, 423(6937), 280-283.

Newman, D. J., Cragg, G. M. (2012). Natural products as sources of new drugs over the 30 years from 1981 to 2010. Journal of Natural Products, 75(3), 311-335.

Oliver, T. H., Heard, M. S., Isaac, N. J., et al (2015). Biodiversity and resilience of ecosystem functions. Trends in Ecology & Evolution, 30 (11). pp. 673-684. doi: https://doi.org/10.1016/j.tree.2015.08.009. Available at https://centaur.reading.ac.uk/47800/

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics, 37, 637-669.

Parmesan, C. (2007). Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology, 13(9), 1860-1872.

Parmesan, C., & Hanley, M. E. (2015). Plants and climate change: complexities and surprises. Annals of Botany, 116(6), 849-864.

Parmesan, C., Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421(6918), 37-42.

Pastor, A., Ivins, E. R., Rignot, E., Smith, B., van den Broeke, M., Velicogna, I., Whitehouse, P., Briggs, K., Joughin, I., ... Wahr, J. (2018). Mass balance of the Antarctic ice sheet from 1992 to 2017. Nature, 558(7709), 219-222.

Pimentel, D., et al. (1997). Economic and environmental benefits of biodiversity. Bioscience, 47(11), 747-757. https://doi.org/10.2307/1313097

Pimm, S. L., et al. (2014). The biodiversity of species and their rates of extinction, distribution and protection. Science, 344(6187), doi: 10.1126/science.1246752

Poloczanska, E. S., Brown, C. J., Sydeman, W. J., et al (2013). Global imprint of climate change on marine life. Nature Climate Change, 3(10), 919-925.

Posey, D. A. (2000). Cultural and Spiritual Values of Biodiversity: A Complementary Contribution to the Global Assessment of Biodiversity. Intermediate Technology Publications.

Primack, R.B. (2014). Essentials of Conservation Biology. (Sixth edition). Sinauer Associates.

Pulwarty, R. S. & Sivakumar, M.V.K.(2014)Information systems in a changing climate: early warning and drought risk management. Weather and Climate Extremes, 3, 14–21.

Rey Benayas, J. M., Newton, A. C., Diaz, A., & Bullock, J. M. (2009). Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science, 325(5944), 1121-1124.

Ricciardi, A., & Simberloff, D. (2009). Assisted colonization is not a viable conservation strategy. Trends in Ecology & Evolution, 24(5), 248-253.

Rignot, E., Mouginot, J., Scheuchl, B., et al (2019). Four decades of mass balance of the Antarctic ice sheet from 1979 to 2017. Proceedings of the National Academy of Sciences (PNAS), 116(4), 1095–1103.

Robock, A. (2000). Volcanic eruptions and climate. Revisions of Geophysics, 38(2), 191-219. https://doi.org/10.1029/1998RG000054

Rocklöv, J., Dubrow, R. Climate change: an enduring challenge for vector-borne disease prevention and control. Nat Immunol 21, 479–483 (2020). https://doi.org/10.1038/s41590-020-0648-y

Root, T. L., Price, J. T., Hall, K. R., et al (2003). Fingerprints of global warming on wild animals and plants. Nature, 421, 57-60.

Rosa, L. (2022) Pollution, one of the five drivers of biodiversity loss. Defenders of Wildlife. Avaliable in: https://defenders.org/blog/2022/12/pollution-one-of-five-drivers-of-biodiversity-loss

Saunois, M., Stavert, A. R., Poulter, B., et al (2020). The Global Methane Budget 2000-2017. Earth System Science. Data, 12(3), 1561–1623.

Sax, D. F., Gaines, S. D. (2008). Invasions and species extinction: the future of native biodiversity on islands. Proceedings of the National Academy of Sciences - PNAS, 105 (Supplement 1), 11490-11497.

Seddon, N., Mace, G. M., Naeem, S. et al (2016). Biodiversity in the Anthropocene: prospects and policy. Proceedings of the Royal Society B: Biological Sciences, 283 (1844).

Simberloff, D., Martin, J. L., Genovesi, P. et al (2013). Impacts of biological invasions: what's what and the way forward. Trends in Ecology and Evolution, 28(1), 58-66.

Smith, P., Soussana, J. F., Angers, D., et al (2019). How to measure, report and verify soil carbon change to realize the potential for soil carbon sequestration for atmospheric removal of greenhouse gases. Global Change Biology, 26(1), 219–241.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (Eds.). (2007). Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Thackeray, S. J., Sparks, T. H., Frederiksen, M., et al (2010). Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. Global Change Biology, 16(12), 3304-3313.

Thomas, C. D., Cameron, A., Green, R. E., et al (2004). Extinction risk from climate change. Nature, 427(6970), 145-148.

Tian, H., Xu, R., Canadell, J. G., et al (2020). A comprehensive quantification of global sources and sinks of nitrous oxide. Nature, 586(7828), 248–256.

Tilman, D., et al. (2001). Diversity and productivity in a long-term pasture experiment. Science, 294(5543), 843-845.

Tittensor, D.P., et al. (2014). A mid-term analysis of progress toward international biodiversity targets. Science, 346(6206), 241-244.

UNFCCC (2015). Paris Agreement. United Nations Framework Convention on Climate Change. Disponível em: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Urban, M. C. (2015). Accelerating extinction risk from climate change. Science, 348(6234), 571-573.

Valladares, F., Matesanz, S., Guilhaumon, F., et al (2014). The effects of phenotypic plasticity and local adaptation on forecasts of species range shifts under climate change. Ecology Letters, 17(11), 1351-1364.

Vasiliev, D. (2022) The Role of Biodiversity in Ecosystem Resilience IOP Conference Series.: Earth Environ. Sci. (1072) DOI 10.1088/1755-1315/1072/1/012012

Visser, M. E., & Both, C. (2005). Shifts in phenology due to global climate change: the need for a yardstick. Proceedings of the Royal Society B: Biological Sciences, 272(1581), 2561-2569.

Volis, S.(2016). How to conserve threatened Chinese plant species with extremely small populations? Plant Diversity, 38(1), 45-52.

Walker, B.H.(1992). Biodiversity and Ecological Redundancy. Conservation Biology.6:18-23

Walther, G. R., Post, E., Convey, P., et al (2002). Ecological responses to recent climate change. Nature, 416, 389-395.

Walther, G. R., Roques, A., Hulme, P. E., et al (2009). Alien species in a warmer world: risks and opportunities. Trends in Ecology & Evolution, 24(12), 686-693.

Warren, R., Price, J., Graham, E., et al (2018). The projected effect on insects, vertebrates, and plants of limiting global warming to 1.5°C rather than 2°C. Science, 360(6390), 791-795.

Warren, R., VanDerWal, J., Price, J., et al (2013). Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. Nature Climate Change, 3(7), 678-682.

Watson, J. Dudley, N., Segan, D. et al. (2014). The performance and potential of protected areas. Nature, 515(7525), 67-73.

Wolf, C., Ripple, W.J.(2017). Range contractions of the world's large carnivores. Royal Society Open Scince, 4(7)

Xenopoulos, M. A., Lodge, D. M., Alcamo, J., et al (2005). Scenarios of freshwater fish extinction from climate change and water withdrawal. Global Change Biology, 11(10), 1557-1564.

Yachi, S. & Loreau, M.(1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis, 96 (4) 1463-1468. https://doi.org/10.1073/pnas.96.4.1463.

Zhang, X., Davidson, E. A., Mauzerall, D. L., et al (2015). Managing nitrogen for sustainable development. Nature, 528(7580), 51–59.