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Interconnected Impacts of Climate Change on Biodiversity, Agriculture and Human Health

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ABSTRACT

This paper explores how climate change affects human health, agriculture, and biodiversity. By reviewing recent studies and data, it looks at how rising temperatures and harsh weather crisis, such as floods and droughts, impact species distribution, yield of crop, and diseases spread. The research shows that higher temperatures are causing many species to migrate, leading to biodiversity loss. It also highlights how extreme weather is reducing crop productivity and elevating the risk of diseases spread by insects. The paper calls for combined efforts to mitigate and adapt to these changes to conserve ecosystems, ensure security of food, and safeguard public health. The study delves into the specifics of how climate change disrupts natural habitats, forcing species to move to new areas where they might not survive. This migration leads to a decline in biodiversity; thus species fail to adapt to new environments. Additionally, the paper examines the climate change impacts on agriculture, noting that extreme weather catastrophes can devastate crops, leading to lower yields and threatening food security. For instance, prolonged droughts can dry up essential water sources, while intense floods can wash away fertile soil and crops. Moreover, the research highlights the elevated risk of diseases borne by vectors, such as dengue fever and malaria, which are becoming more prevalent as changing precipitation patterns and warmer temperatures create suitable conditions for disease-carrying insects. This shows a significant threat to public health, especially in regions that are already vulnerable. In conclusion, the paper emphasizes the need for integrated strategies that combine mitigation and adaptation efforts. By minimizing greenhouse gas emissions and implementing adaptive strategies, such as developing climate-resilient crops and improving public health infrastructure, we can better protect our ecosystems, ensure stable food supplies, and safeguard human health against the adverse consequences of climate change.

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1. Introduction

Climate change represents a critical global challenge, characterized by substantial alterations in climatic elements such as temperature and precipitation over extended periods (WMO, 1992). These shifts are predominantly attributed to intensified human activities that have disrupted the atmospheric composition (IPCC, 2007). Since 1750, greenhouse gas concentrations, including methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), have increased by approximately 150%, 40%, and 20%, respectively (IPCC, 2014). CO_2 emissions surged from 22.15 billion metric tons in 1990 to 36.14 billion metric tons in 2014 (Abeydeera et al., 2019). The global average temperature has been rising at a rate of 0.15–0.20°C per decade since 1975 (NASA Earth Observatory), with projections indicating a potential rise of 1.4–5.8°C by the end of the 21st century (Arora et al., 2005). Atmospheric CO_2 levels climbed from 315.98 ppm in 1959 to 411.43 ppm in 2019 (NOAA, 2020), with CO_2 contributing 65% of total greenhouse gas emissions, primarily from fossil fuels and industrial activities (IPCC, 2014).

The rising levels of greenhouse gases have profound implications for global temperatures. These gases, including CO_2, ozone (O_3), and water vapor (H_2O), absorb thermal radiation emitted by the Earth's surface, causing a warming effect known as the greenhouse effect. Since 1850, the global average temperature has increased by approximately 1–1.2°C. Land temperatures have risen nearly twice as fast as ocean temperatures, with land warming by 1.32 ± 0.04°C compared to the 1951–1980 average, while ocean surface temperatures have increased by 0.59 ± 0.06°C. The Northern Hemisphere, due to its greater landmass, has experienced more pronounced warming than the Southern Hemisphere, with polar regions exhibiting the most extreme temperature increases, resulting in accelerated glacial melting (Richie et al., 2017). The IPCC continues to play a pivotal role in evaluating climate science, identifying risks, and proposing solutions. The Paris Agreement of 2015 seeks to limit global temperature increases to well below 2°C above pre-industrial levels, striving for a 1.5°C cap (UNFCCC, 2015). The IPCC's Sixth Assessment Report underscores the urgency of decisive climate action, highlighting the interconnectedness of climate, ecosystems, and human societies (IPCC, 2022).

Historically, climate change has triggered catastrophic events, leading to the widespread destruction of urban areas and wildlife habitats and causing significant loss of life and injuries. Temperature and precipitation changes are the primary drivers of climate impacts. Rising temperatures and CO_2 levels have been linked to alterations in the hydrological cycle, including precipitation and evaporation patterns, and an increase in the frequency and intensity of extreme weather events such as floods, cyclones, and droughts, which severely affect biodiversity (Adler et al., 2009; Rinawati et al., 2013). Persistent temperature increases can lead to disasters such as wildfires and heat waves. July 2023 was recorded as the hottest month in 190,000 years, marking a transition from a global warming phase to a "global boiling" era (Mostafa et al., 2023). These phenomena, coupled with rising sea levels from polar ice cap melting, significantly threaten coastal regions and ecosystems (NASA, 2023).

Biodiversity, encompassing the diversity of genes, species, and ecosystems, underpins ecosystem stability and resilience (Cardinale et al., 2012). It facilitates critical functions such as nutrient cycling, climate regulation, and air and water purification (Chapin et al., 2000). However, biodiversity faces severe threats from habitat destruction, pollution, overexploitation, and climate change (Pimm et al., 2014). Rising global temperatures and shifting climatic conditions disrupt species distributions and ecosystem dynamics, increasing extinction risks (Bellard et al., 2012). Coral reefs, highly sensitive to temperature changes, are experiencing widespread bleaching, imperiling marine biodiversity (IPCC, 2022). The projected extinction of over a million terrestrial species within 50 years highlights the critical need for conservation efforts (Thomas et al., 2004).
Climate change poses significant risks to global food and nutritional security. Elevated greenhouse gas emissions have intensified global temperatures, which are expected to rise by 2°C by the end of the century, leading to economic losses and agricultural disruptions. While higher CO_2 levels can enhance plant growth, rising temperatures shorten crop cycles, increase pest infestations, and affect soil microbial communities (Malhi et al., 2021). Agriculture, accounting for approximately 15% of global emissions, faces challenges from extreme weather events, affecting yields and food security, particularly in already vulnerable regions (World Bank, 2020).

Human health is also at significant risk from climate change, with extreme weather events like heatwaves, storms, and floods directly causing injuries, illnesses, and deaths. The World Health Organization estimates that climate change could lead to an additional 250,000 deaths annually between 2030 and 2050 due to heat stress, malnutrition, malaria, and diarrhea (WHO, 2023). Additionally, climate-induced habitat changes promote the spread of vector-borne diseases such as malaria and dengue fever (USEPA, 2024). Indirect effects include exacerbated air pollution, contributing to millions of deaths annually, and intensifying respiratory and cardiovascular diseases (WHO, 2023).

Addressing climate change requires integrated mitigation and adaptation strategies. Mitigation efforts focus on reducing greenhouse gas emissions through renewable energy adoption, energy efficiency, and carbon capture technologies (Fawzy et al., 2020). Adaptation strategies include developing climate-resilient infrastructure, efficient water management, and resilient crops (World Bank, 2020). Protecting and restoring ecosystems enhances carbon sequestration and provides natural defenses against extreme weather (World Economic Forum, 2022). Global cooperation and urgent action are essential to limit warming to 1.5°C, peak emissions by 2025, and reduce them by 43% by 2030 (IPCC, 2022). This paper explores the intricate impacts of climate change on biodiversity, agriculture, and human health, offering a multidisciplinary perspective to emphasize the urgency of global mitigation and adaptation efforts.

2. Climate change

Climate change is among the most critical challenges confronting the modern world. It is defined by significant long-term changes in meteorological factors such as temperature and precipitation (WMO, 1992). Recent studies reveal that these climatic shifts are largely attributed to heightened human activities that have altered the atmospheric composition on a global scale (IPCC, 2007). Since 1750, greenhouse gas concentrations—including methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O)—have increased by approximately 150%, 40%, and 20%, respectively (IPCC, 2014). Carbon dioxide, which accounts for the largest proportion of these emissions, surged from 22.15 billion metric tons in 1990 to 36.14 billion metric tons by 2014, as depicted in Figure (1) (Abeydeera et al., 2019).

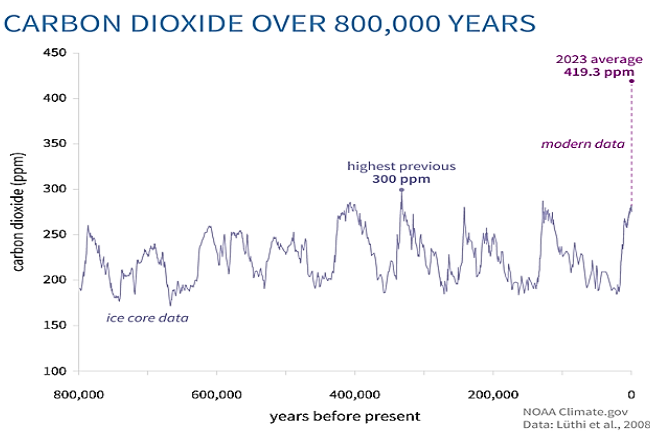

Fig. (1): illustrates atmospheric carbon dioxide (CO_2) levels, measured in parts per million (ppm), over the past 800,000 years using ice-core data, represented by the light purple line. This historical data is compared to the CO_2 concentration in 2022, indicated by the bright purple dot. The variations in the line reflect periods of ice ages (lower CO_2 levels) and warmer interglacial phases (higher CO_2 levels). Throughout this extensive period, CO_2 concentrations never surpassed 300 ppm, as highlighted by the light purple dot representing levels from 300,000 to 400,000 years ago. However, over the last 60 years, CO_2 levels have risen at a rate 100 times faster than any previous natural increases. On a geological scale, the sharp rise in CO_2 from the end of the last ice age to the present, represented by the dashed purple line, appears almost instantaneous. This graph, developed by NOAA Climate.gov, is based on data from Lüthi et al. (2008) via the NOAA NCEI

Since 1975, the average global temperature has been rising at a rate of 0.15–0.20°C per decade (NASA Earth Observatory). Projections suggest that by the end of the 21st century, global temperatures could increase by 1.4–5.8°C (Arora et al., 2005). Atmospheric CO_2 concentrations have grown significantly, from 315.98 ppm in 1959 to 411.43 ppm in 2019 (NOAA, 2020). Carbon dioxide constitutes a major portion of greenhouse gases, with 65% originating from fossil fuel use and industrial processes, 11% from forestry and other land-use activities, followed by methane (16%), nitrous oxide (6%), and fluorinated gases (2%) (IPCC, 2014). The rising levels of greenhouse gases have profound impacts on global temperatures. These gases, including CO_2, ozone (O_3), and water vapor (H_2O), absorb thermal radiation emitted from the Earth's surface and atmosphere, thereby causing warming—a phenomenon referred to as the greenhouse effect. Since 1850, the global average temperature has risen by approximately 1–1.2°C. Land temperatures have increased about twice as much as ocean temperatures, with land temperatures rising by 1.32 ± 0.04°C compared to the 1951–1980 average (refer to Figures 2 and 3), while ocean surface temperatures (excluding sea ice regions) have increased by 0.59 ± 0.06°C.

The Northern Hemisphere, with its larger landmass, has experienced a greater average temperature rise (1.31°C) compared to the Southern Hemisphere (0.91°C), leading to a global average increase of 1.11°C since 1850. The most severe temperature increases have been recorded in polar regions, contributing to significant glacial melting (Richie et al., 2017).

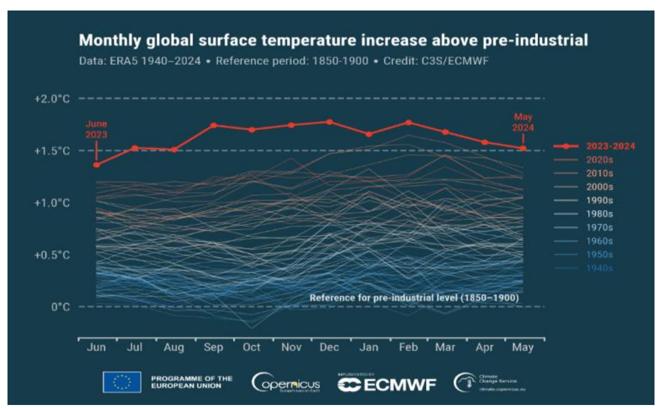

Fig. (2): Monthly global surface air temperature anomalies (°C) relative to 1850–1900 from January 1940 to May 2024, plotted as a time series for all 12-month periods spanning June to May of the following year. The 12 months from June 2023 to May 2024 are shown with a thick red line, while all other 12-month periods are shown with thin lines shaded according to the decade, from blue (1940s) to brick red (2020s). Data source: ERA5. Credit: Copernicus Climate Change Service /ECMWF [https://climate.copernicus.eu/surface-air-temperature-*may-2024*.](https://climate.copernicus.eu/surface-air-temperature-may-2024)

3. Role of Organizations like the IPCC and Initiatives like the Paris Agreement

The Intergovernmental Panel on Climate Change (IPCC) plays a vital role in analyzing the science behind climate change, evaluating its impacts and future risks, and recommending strategies for adaptation and mitigation. Its extensive reports serve as the scientific foundation for shaping international climate policies and facilitating negotiations.

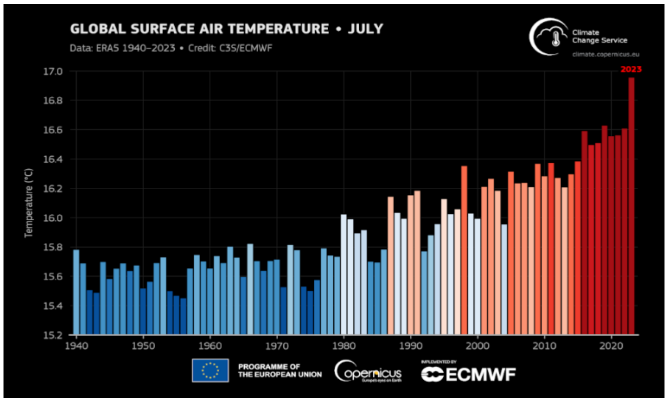

Fig. (3): Global Surface Air Temperature (°C) Relative to 1940–2023: The year 2023 has emerged as the hottest year recorded in recent history. Notably, July 2023 has been identified as the warmest month since pre-industrial times, underscoring a concerning trend in global warming and climate change. This sharp increase in temperature highlights the critical need for urgent action to address environmental challenges and mitigate climate-related impacts (The Conversation, 2023). https://theconversation.com/global-temperatures-are-off-the-charts-for-a-reason-4-factors-driving-2023s-extreme-heat-and-climate-disasters-209975.

A key milestone in addressing climate change is the Paris Agreement, adopted in 2015. This accord seeks to limit global temperature increases to well below 2°C above preindustrial levels, with an aspirational goal of capping the rise at 1.5°C. It stresses the importance of global collaboration in reducing greenhouse gas emissions and building resilience to climate-related challenges (UNFCCC, 2015). The IPCC's Sixth Assessment Report (AR6) emphasizes the critical need for bold and accelerated measures to address climate risks. It highlights the interconnectedness of climate, biodiversity, and human societies while urging immediate and more decisive actions to mitigate climate change and adapt to its effects (IPCC, 2022).

By integrating scientific research and promoting international cooperation, organizations like the IPCC and initiatives such as the Paris Agreement are indispensable in directing global efforts to combat climate change and ensure the well-being of future generations.

4. The Impacts of Climate Change on Biodiversity and Disasters

Extreme weather events, such as floods, cyclones, and droughts, driven by climate change, have significant adverse effects on biodiversity. Natural disasters, including earthquakes, extreme temperatures, volcanic eruptions, landslides, storms, wildfires, floods, and droughts, exacerbate biodiversity loss. Countries frequently experiencing these catastrophic events face severe consequences for their ecosystems and species diversity (Habibullah et al., 2022).

From 2000 to 2019, there was a marked increase in climate-related disasters globally. According to the UN Office for Disaster Risk Reduction (UNDRR), this period witnessed 7,348 major disaster events, resulting in 1.23 million fatalities, affecting 4.2 billion individuals, and causing approximately $2.97 trillion in economic damages. In comparison, the preceding two decades (1980–1999) reported 4,212 disasters, 1.19 million deaths, and $1.63 trillion in economic losses. This rise is primarily attributed to climate-related disasters, which surged from 3,656 events in 1980–1999 to 6,681 in 2000–2019. Floods and storms were the most frequent events, with floods more than doubling from 1,389 to 3,254, and storms increasing from 1,457 to 2,034. Additionally, the frequency of droughts, wildfires, and extreme temperature events saw significant growth. Between 2020 and 2024, climate-related disasters have continued to rise in frequency and intensity, causing immense human suffering and economic damage. For example, the United States alone experienced 20 separate billion-dollar weather and climate disasters in 2021, amounting to approximately $145 billion in damages (NOAA, 2022).

One notable climate-related disaster was Typhoon Haiyan, also known as Super Typhoon Yolanda, which struck Southeast Asia, particularly the Philippines, from November 3–11, 2013 (NOVA, 2013). The storm formed from a low-pressure system in the western Pacific Ocean and rapidly developed into a Category 5-equivalent super typhoon due to abnormally warm sea surface temperatures in the region. These elevated temperatures provided the energy required for rapid intensification, coupled with favorable wind patterns and deep warm water layers (NOAA, 2013). At its peak, Haiyan recorded sustained winds of up to 195 mph (315 km/h), making it one of the most powerful typhoons ever observed (Climate Central, 2013).

The destruction caused by Typhoon Haiyan was catastrophic, particularly in the Visayas region of the Philippines. The disaster claimed the lives of approximately 6,352 people, left around 1,771 missing, and caused injuries to thousands. The storm also led to significant losses in livestock and wildlife, although exact figures are not well-documented. Over 1.1 million homes were damaged or destroyed, and critical infrastructure, including roads, bridges, and hospitals, was severely impacted (Lagmay et al., 2015).

Fig. (4): Houses destroyed by Typhoon Haiyan in Tacloban, on the eastern island of Leyte in the Philippines. Noel celis, AFP/Getty images https://www.usatoday.com/story/news/world/2013/11/08/typhoon-haiyan-philippines/3473495/.

The Australian bushfires of 2016 and 2019 highlighted the escalating impact of climate change on natural disasters. In 2016, Tasmania experienced significant bushfires, particularly during January and February. These fires devastated over 123,000 hectares of land, including ancient forests within the World Heritage-listed Tasmanian Wilderness, resulting in severe ecological damage (Climate Council, 2016). The 2019–2020 bushfire season, known as "Black Summer," was even more catastrophic. Beginning in June 2019 and lasting into early 2020, the fires swept across southeastern Australia, especially New South Wales and Victoria. Approximately 11 million hectares were burned, over 3,000 homes were destroyed, and at least 33 lives were lost (BBC News, 2020).

Climate change significantly intensified these bushfires. Rising global temperatures have created hotter and drier conditions, increasing both the likelihood and severity of wildfires. Research indicates that climate change heightened the risk of the extreme weather conditions that fueled the 2019–2020 bushfires by at least 30% (Science News, 2020). Prolonged drought and record-breaking temperatures during this period were directly attributed to human-induced climate change, contributing to the increased frequency and intensity of such destructive fires (BBC News, 2020).

In turn, wildfires themselves contribute to climate change by releasing substantial amounts of greenhouse gases into the atmosphere. The 2019–2020 Australian bushfires, for instance, emitted an estimated 830 million tons of CO_2—equivalent to 1.6 years of Australia's typical emissions (DCCEEW, 2021). The combustion of large amounts of biomass not only produces CO_2 but also releases potent greenhouse gases such as methane and nitrous oxide, further exacerbating global warming (Science News, 2021). These emissions amplify the concentration of greenhouse gases in the atmosphere, accelerating climate change and leading to more frequent and severe weather events, rising sea levels, and widespread disruptions to ecosystems and biodiversity (BBC, 2020).

This interconnected cycle underscores the urgent need for effective wildfire management and comprehensive climate mitigation strategies to address both the causes and consequences of such disasters.

Fig. (5): Australia bushfire Australian wildfires destroy homes in New South Wales (thestar.com)

The 2023 disaster in Derna, Libya, was a devastating event intensified by the impacts of climate change. On September 10, 2023, Storm Daniel struck the region, delivering unprecedented rainfall. The heavy downpour caused the collapse of two dams, unleashing approximately 30 million cubic meters of water into the city of Derna. This triggered catastrophic flooding, resulting in the deaths of nearly 4,000 people, with thousands more reported missing or injured (Marshall, 2023). The floods obliterated entire neighborhoods, severely damaged infrastructure and homes, and displaced tens of thousands of residents (Rowlatt, 2023).

Climate change significantly amplified the storm's intensity, as warmer sea surface temperatures and increased atmospheric moisture contributed to the extreme rainfall (BBC News, 2023). This tragic event highlights the urgent need for enhanced climate resilience measures and robust disaster preparedness strategies, particularly in regions highly vulnerable to climate-related hazards.

In 2024, climate change has significantly contributed to various disasters, as shown in Figure (7), ranging from severe floods to intense heatwaves. In January, southern Brazil experienced devastating floods, causing extensive property damage and displacing thousands of residents (Smith, 2024). By March, a severe drought struck the Amazon, exacerbating deforestation and threatening biodiversity (Johnson, 2024). In May, India faced an unprecedented heatwave, with temperatures soaring above 50°C, leading to widespread health crises and fatalities (Kumar, 2024), as shown in Figure (8). June saw extreme weather in the United States, including tornado outbreaks and severe storms, resulting in billions of dollars in damages (Williams, 2024). These events highlight the escalating impact of climate change, as rising global temperatures and shifting weather patterns intensify the frequency and severity of natural disasters (Brown, 2024; Davis, 2024).

Fig. (6): In Derna, cars are stacked on top of rubble following the devastating flash floods brought on by Storm Daniel in September 2023. https://www.nrc.no/feature/2024/can-the-world-afford-another-crisis/.

To effectively combat the persistent and devastating impacts of climate change, immediate and sustained action is imperative. The IPCC underscores the necessity of reducing greenhouse gas emissions, transitioning to renewable energy sources, and enhancing energy efficiency (IPCC, 2023). Certain climate-related disasters, such as the melting of polar ice caps, represent irreversible tipping points that can only be managed to mitigate further damage (Smith, 2024). However, for events that have not yet reached these critical thresholds, proactive measures can still yield significant benefits. By addressing these issues now, we can avert future catastrophes and safeguard our planet for future generations (Johnson, 2024).

Hurricane Milton struck Florida on October 8, 2024, causing widespread devastation, resulting in at least 17 confirmed deaths and numerous injuries (CBS News, 2024). This powerful Category 3 storm brought destructive winds exceeding 100 mph, torrential rain, and spawned tornadoes, leading to significant damage to infrastructure, including the sheriff's facility in St. Lucie County and the Venice Fishing Pier (CBS News, 2024). The economic impact is substantial, with over 3 million people left without power and extensive damage to properties and businesses, costing billions in repairs and recovery (AP News, 2024). Scientists attribute the increasing intensity and frequency of hurricanes like Milton to climate change, which exacerbates the severity of such natural disasters by warming ocean temperatures and altering weather patterns (MSN, 2024).

Fig. (7): shows the events of extreme weather occurred in 2024 as the map shows different disasters around the globe as drought represented by yellow circles in Africa, Wildfire represented by red circles in Australia, North and South America . , https://www.dw.com/en/is-climate-change-behind-all-extreme-weather-events/a-69107065

Fig. (8): On May 2, 2024, firefighters rescued a man and his dog from a flooded area in the city center of São Sebastião do Caí, located in Rio Grande do Sul, Brazil. The severe storm that hit the region has resulted in 13 fatalities, marking the “worst disaster” in the state’s history. President Luiz Inácio Lula da Silva visited the affected area on Thursday. (Photo by Anselmo Cunha / AFP via Getty Images. All rights reserved.). https://newsroom.churchofjesuschrist.org/article/church-of-jesus-christ-responds-to-major-flooding-in-rio-grande-do-sul-brazil.

4.1. Climate Change Impacts on biodiversity

Biodiversity encompasses the richness and variety of life on Earth, spanning from genes to ecosystems. It involves evolutionary, ecological, and cultural processes that sustain life, making it a crucial and intricate feature of our planet. Without biodiversity, life would be unsustainable (Wilson, 1988).

Biodiversity arises from the divergence of organisms through evolutionary processes. When species become so distinct that they can no longer interbreed, they are considered separate species. Conversely, organisms capable of reproducing with each other belong to the same species (Santamaría & Méndez, 2012). Scientists estimate there are around 11 million species of plants and animals in existence (Chapman et al., 2009).

Fig. (9): Devastation in Florida, October 2024: Floodwaters from Hurricane Milton engulf a tree, submerge a house up to the windows, and drown a mailbox, illustrating the sheer force of the storm and the urgent need for disaster preparedness and climate action. Hurricane Milton latest: 'Miracle' baby born after perilous journey; man saved clinging to cool box - as deaths rise | US News | Sky News.

However, only about 1.2 million species have been identified and described so far, most of which are insects (Silvestro, 2022). This means millions of organisms remain a mystery. The high variety of organisms and their complex interactions with each other and their surroundings enhance ecosystem stability (Strok, 2009).

Biodiversity boosts ecosystem productivity, where each species, no matter how small, plays an important role. For example, a larger number of plant species means a greater variety of crops. Greater species diversity ensures natural sustainability for all life forms (Shah, 2014). Biodiversity also has several functions on Earth, such as maintaining ecosystem balance by recycling nutrients, combating pollution, stabilizing the climate, protecting water resources, and preserving soil health. It provides essential biological resources, including medicines, food for humans and animals, ornamental plants, wood products, and diverse genetic stock across species and ecosystems. Beyond ecological functions, biodiversity contributes to recreation, tourism, cultural value, education, and scientific research (Oliver et al., 2015).

Despite the United Nations (2024) describing biodiversity as the strongest natural defense against climate change, it has not prevented the harsh effects of climate on biodiversity. Human-induced environmental changes such as habitat loss, degradation, overexploitation of bioresources, and the introduction of alien species, along with climate change, affect biodiversity and ecosystems (Badr & El-Shazly, 2024). In recent decades, a massive loss of biodiversity has led to the initiation of the sixth mass extinction crisis due to human-induced environmental changes (Leech & Crick, 2007; Sodhi & Ehrlich, 2010). Some scientists estimate that half of all species on Earth will be wiped out within the next century. Climate change is anticipated to have various impacts on biodiversity, influencing species and ecosystems in multiple ways (Parmesan, 2006). It is expected to become one of the primary drivers of the decline in African biodiversity over the next century (Sala et al., 2000; Bellard et al., 2012; Midgley & Bond, 2015).

The two most common indicators of climate change are a rise in the average global temperature and severe, unpredictable weather patterns. Variations in temperature and precipitation can lead to shifts in species distribution and abundance, as well as changes in the timing of natural events such as migration, breeding, fruiting, and flowering. These changes can disrupt the delicate balance among species, potentially leading to extinctions, shifts in species composition, and population declines (Shivanna, 2022). One of the most direct effects of climate change is the alteration of habitat suitability for many species. As temperatures increase, species are compelled to migrate to higher latitudes or elevations to find suitable climate conditions (Thomas et al., 2004). This can result in heightened competition for resources and potential conflicts with resident species (Walther et al., 2002). Additionally, changes in temperature and precipitation patterns can disrupt the timing of biological events, such as flowering and migration, causing mismatches between species interactions and potential declines in population sizes (Visser & Both, 2005). Moreover, Hooper et al. (2005) emphasized that the loss of biodiversity can also diminish the resilience of ecosystems to other stresses, such as invasive species or disease outbreaks.

Terrestrial species and ecosystems have evolved to flourish under specific conditions, from the range of temperatures a species can endure, known as the species' climate envelope, to the seasons that dictate their mating and migration patterns (Xu & Prescott, 2024). According to the IPCC (2023), global temperatures are projected to rise by more than 1.5°C within the next 20 years. This abrupt and severe change will either compel many species to adapt, if possible, or drive them towards extinction. If global temperatures rise by 1.5 degrees Celsius, up to 14 percent of terrestrial plants and animals are expected to face a significant risk of extinction (IPCC, 2021). The outlook becomes even more dire with further temperature increases; for example, a 3-degree Celsius rise could threaten up to 29 percent of land species with extinction (IPCC, 2021).

Plant and animal species have adapted to their native habitats over thousands of years. As temperatures rise in their native habitats, species tend to migrate to higher altitudes and towards the poles in search of suitable temperatures and other environmental conditions (Bolan et al., 2023). Numerous reports document climate change-induced shifts in the distributional ranges of both plant and animal species (Lobell et al., 2011). According to IPCC (2021), half of the species have moved toward the poles or to higher elevations. Populations unable to migrate or adapt, such as certain plant and insect species, face the risk of local extinction. Consequently, this will reduce the genetic diversity of the entire species, making it more susceptible to pests, diseases, and other pressures (Harvey, 2023).

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), approximately one million animal and plant species are currently at risk of extinction. Climate change significantly contributes to this crisis, impacting at least 10,967 species listed on the IUCN Red List. Projections indicate that if global temperatures rise by 2°C by 2100, around 18% of terrestrial species will face a high risk of extinction. More sensitive species, such as insect pollinators and salamanders, could see over 30% facing severe risks under this scenario (IPBES, 2019).

The Bramble Cay melomys (Melomys rubicola), also known as the mosaic-tailed rat, was a diminutive rodent species endemic to Bramble Cay, a small island in the Torres Strait near Papua New Guinea. Documented by Europeans in 1845, this species was distinguished by its unique habitat on the low-lying cay, which rises to a maximum of 10 feet above sea level (Gynther et al., 2016). The Bramble Cay melomys is notably the first mammal to be declared extinct due to anthropogenic climate change figure (10). The primary driver of its extinction was the rising sea levels and the increased frequency of extreme weather events, which led to the inundation of its habitat. Between 1998 and 2014, the island's habitable area above high tide diminished significantly, resulting in a substantial loss of vegetation and habitat for the melomys (Gynther et al., 2016). The last confirmed sighting of the species occurred in 2009, and despite extensive searches, no individuals were found in subsequent years (Bell, 2019).

Fig. (10): The Bramble Cay melomys lived on a tiny island in Australia's far north.
https://cosmoso.net/10-endangered-species-well-never-see-again-in-2017/no-10/.

The golden toad (Incilius periglenes), a small and vividly colored amphibian, was native to the high-altitude cloud forests of Monteverde, Costa Rica (figure 11).

The males were particularly notable for their bright orange skin, while the females had more subdued olive tones with red spots. First described in 1966, this species had an extremely limited range, confined to just a few square kilometers (Pounds et al., 1999). The extinction of the golden toad is a striking example of the severe impact of climate change on biodiversity. Last observed in 1989, its extinction was officially recognized in 2004. Researchers attribute its demise to a combination of factors, mainly climate change and disease. The habitat of the golden toad was significantly altered due to rising temperatures and changes in precipitation patterns, exacerbated by the El Niño events of the late 1980s. These climatic changes led to drier conditions, reducing the availability of breeding sites and increasing the toads' susceptibility to pathogens, particularly the chytrid fungus (Pounds et al., 1999; CBS News, 2022).

Fig. (11): ToadLast seen in 1989, Costa Rica's golden toad (pictured) is perhaps the most famous of the "lost amphibians"
.https://www.nationalgeographic.com/science/article/100810-ten-lost-extinct-amphibians-frogs-science-

The polar bear (Ursus maritimus), a powerful carnivorous mammal, is native to the Arctic region (see figure 12), primarily living on sea ice where it hunts seals. Its white fur provides camouflage in its icy environment, and the species relies heavily on sea ice for hunting and breeding (Pagano et al., 2018). Currently, polar bears face a grave threat due to climate change. The rapid melting of Arctic sea ice, essential for their survival, is the main driver of this threat. As global temperatures rise, the extent and thickness of sea ice diminish, forcing polar bears to spend longer periods on land where food is scarce. This has led to increased instances of starvation and reduced reproductive success (Pagano et al., 2018; Amstrup et al., 2020). If current trends continue, projections indicate that polar bears could face near extinction by the end of the century (Amstrup et al., 2020).

The Adélie penguin (Pygoscelis adeliae), native to the Antarctic continent, is known for its distinctive black and white plumage and reliance on sea ice for breeding and foraging.

Fig. (12): The loss of sea ice habitat from climate change is the biggest threat to the survival of polar bears. https://www.ndtv.com/world-news/polar-bear-appears-in-iceland-for-1st-time-in-8-years-shot-dead-by-police-6616082.

Over millennia, these penguins have adapted to the harsh Antarctic environment, surviving glacial expansions and fluctuations in sea ice (Cimino et al., 2016). However, the Adélie penguin now faces significant threats from climate change (figure 13). Rising temperatures and changing precipitation patterns, especially along the rapidly warming West Antarctic Peninsula, are transforming their habitat. These climatic changes have reduced sea ice, which is crucial for the penguins' breeding and foraging activities. Additionally, warmer sea surface temperatures have affected the availability of their main food sources, such as krill and fish, further contributing to their decline (Cimino et al., 2016; Sidder, 2016). Projections indicate that if current climate trends continue, up to 60% of Adélie penguin colonies could decline by the end of the century due to the loss of suitable breeding and foraging habitats and prolonged periods of elevated sea surface temperatures (Cimino et al., 2016).

Fig. (13): Melting sea ice due to temperature rise has a direct impact on Adélie penguin survival. https://true-wildlife.blogspot.com/2010/12/adelie-penguin.html.

The bumblebee, particularly species like the Western bumblebee (Bombus occidentalis), is an essential pollinator, known for its large, fuzzy body and distinctive buzzing sound. Bumblebees play a crucial role in pollinating numerous wildflowers and agricultural crops, such as tomatoes, peppers, and cranberries (Everett, 2023). Climate change has significantly contributed to the decline of bumblebee populations. Rising temperatures and the increased frequency of extreme weather events, such as heatwaves, have severely impacted their habitats. Bumblebees, adapted to cooler climates, are ill-equipped to withstand prolonged periods of high temperatures. These conditions not only cause direct heat-related mortality but also devastate native floral communities, reducing the availability of forage at critical times in the bumblebee colony's development (Everett, 2023; Miller-Struttmann, 2024). The extinction of bumblebees would have profound repercussions on ecosystems (figure 14). As key pollinators, their decline would lead to reduced pollination of many plants, affecting both wild ecosystems and agricultural productivity. This could result in decreased biodiversity, as plants that rely on bumblebees for pollination fail to reproduce, and could also impact food security due to lower crop yields (Everett, 2023; Miller-Struttmann, 2024).

Fig. (14): Climate change is pushing bumblebees to the brink of extinction, threatening the delicate balance of our ecosystems and the future of our food supply. https://blog.nature.org/2014/03/19/plight-of-bumble-bee-native-pollinators-ecosystem-services/.

The Asian elephant (Elephas maximus), a highly intelligent and magnificent mammal, has historically inhabited a diverse range of ecosystems across South and Southeast Asia. These elephants are known for their crucial cultural and ecological roles, including forest regeneration through seed dispersal. Unfortunately, their populations have been steadily declining due to various human-induced pressures (WWF, 2023). Climate change has exacerbated the threats faced by Asian elephants. Rising temperatures and altered precipitation patterns have led to significant habitat degradation and fragmentation, reducing the availability of fresh water and suitable foraging grounds essential for their survival. Additionally, increased temperatures have heightened the risk of heat stress and disease, further endangering these animals (WWF, 2023; WildAid, 2023).

The extinction of Asian elephants would have profound ecological consequences. As keystone species (figure 15), their decline would disrupt forest ecosystems, negatively affecting biodiversity and the overall health of the habitats they support. The loss of these elephants would also erode the cultural heritage of the regions where they have been revered for centuries (WWF, 2023; WildAid, 2023).

Fig. (15): Climate change threatens the survival of the Asian elephant, jeopardizing vital ecosystems and centuries-old cultural traditions. https://www.khao-sok-riverside-cottages.com/asian-elephant-khao-sok-national-park-elephant/

Climate change presents a serious threat to plant species, leading to habitat loss, altered growth conditions, and increased susceptibility to pests and diseases. Rising temperatures and changing precipitation patterns have already caused significant declines in many plant populations. For example, tropical plant species in regions like Monteverde, Costa Rica, are experiencing severe losses due to warmer and drier climates (Hollenbeck, 2024). Additionally, nearly 40% of global plant species are now threatened with extinction, including critical crops such as wild relatives of potatoes (*Solanum spp*.), avocados (*Persea americana*), and vanilla (*Vanilla planifolia*) (Pavid, 2020). The impacts of climate change extend to alpine plants such as the Glacier lily (*Erythronium grandiflorum*), Snow lotus (*Saussurea laniceps*) (figure 16), and *Phlomis aurea* (Serag et al., 2018), which are struggling to survive as their high-altitude habitats warm and shrink (Cho, 2022). Additionally, the distribution of some species, such as *Alkanna orientalis*, is affected (Mostafa & Mansour, 2020). These declines disrupt ecosystems, reduce biodiversity and impair essential ecosystem services like carbon sequestration, soil stabilization, and water regulation.

The loss of plant diversity also affects agricultural productivity and food security, posing a direct threat to human livelihoods. For instance, the decline of wild relatives of staple crops can reduce genetic diversity, making cultivated varieties more vulnerable to pests, diseases, and changing climate conditions (Cho, 2022).

While many species will be negatively impacted by climate change, some may benefit from an expanded range of available habitats. This, combined with the increased global movement of people and goods, has led to a rise in the introduction and establishment of species outside their natural ranges. These invasive species aggressively compete with native species for resources, which negatively impacts local biodiversity. As the climate changes, invasive species can move into new habitats, competing with native species for food, shelter, and space. They can also introduce new diseases (Ziska, 2022).

Fig. (16): "Climate change poses a significant threat to various plants, including the Glacial Lily (*Erythronium grandiflorum*), Potato (*Solanum tuberosum*), Vanilla (*Vanilla planifolia*), and Avocado (*Persea americana*). Rising temperatures altered precipitation patterns, and increased pest and disease pressures are pushing these species towards extinction.
https://www.synergytaste.com/insights/the-story-of-vanilla-and-how-it-became-the-most-prolific-flavor-blog/. https://www.monaconatureencyclopedia.com/solanum-tuberosum/?lang=en.,https://en.wikipedia.org/wiki/Avocado.https://www.pnwflowers.com/flower/erythronium-grandiflorum

4.2. Marine species

Global warming is causing ocean temperatures to rise, leading to higher sea levels and changes in ocean currents that affect species' access to food and their reproductive patterns. Additionally, the increased carbon dioxide in the atmosphere dissolves into the ocean, resulting in ocean acidification. This acidification challenges marine creatures like crabs and sea urchins, impacting their ability to form shells and exoskeletons. As the ocean's pH becomes more acidic due to absorbed carbon dioxide, shell-forming organisms such as oysters and certain types of plankton struggle to build and maintain their calcium carbonate shells. This can have far-reaching consequences for the entire marine food web, as these organisms are vital food sources for many marine species (Guinotte & Fabry, 2008).

Among marine species, corals are the most affected by rising temperatures and ocean acidity (figure 17). Corals live in a symbiotic relationship with algae, which provide color and photosynthates to the corals. Corals are extremely sensitive to heat and acidity; even a 2–3°F increase in ocean water temperature can cause the expulsion of symbiotic algae from their tissues, leading to bleaching (Hoegh-Guldberg et al., 2017). Prolonged bleaching conditions result in coral death. Nearly one-third of the Great Barrier Reef, the world's largest coral reef system that supports a significant Australian tourism industry, has died due to global warming (Hughes et al., 2018). According to the IPCC Sixth Assessment Report, just 1.5 degrees Celsius of warming could destroy up to 90 percent of tropical coral reefs, which are home to an incredible diversity of organisms and form the basis of many fisheries (IPCC, 2021). Experts warn that if greenhouse gas emissions persist at their current rate, coral reefs will be unrecognizable within the next 50 years (NOAA, 2021). Coral reefs provide suitable habitats for thousands of species, including sharks, turtles, and whales. If corals die, the entire ecosystem will be disrupted.

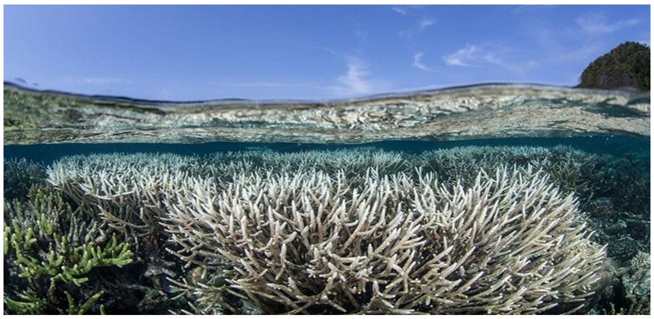

Fig. (17): Warming oceans are causing coral bleaching, like this reef in Indonesia. © Ethan Daniels/ Shutterstock (https://www.nhm.ac.uk/discover/how-are-climate-change-and-biodiversity-loss-linked.html).

Marine ecosystems are more sensitive to climate change than terrestrial ones, possibly because land species have more options for adaptation, such as migrating to higher altitudes (National Geographic, 2019). Melting ice in the Arctic region due to global warming threatens the survival of native animals such as polar bears, Arctic foxes, and Arctic wolves (WWF, 2022). Rising sea levels also lead to the extinction of many endangered and endemic plant and animal species in submerged coastal areas and islands. Over 180,000 islands around the globe contain 20% of the world's biodiversity (Bellard et al., 2013). According to the Centre for Biological Diversity (2013), 233 federally protected threatened and endangered species in 23 coastal states are at risk if rising sea levels are unchecked.

Recently, more than 100 Aquatic Science Societies, representing over 80,000 scientists from seven continents, sounded the climate alarm (Bonar, 2021). They highlighted the effects of climate change on marine and aquatic ecosystems and called on world leaders and the public to undertake mitigation measures to protect and sustain aquatic systems and their services. The impacts of climate change on marine biodiversity are not only concerning from an environmental perspective but also have significant implications for human populations that rely on the oceans for food, livelihoods, and cultural practices. In many coastal and island communities, fishing and tourism industries are the main sources of income and sustenance, and the decline of marine biodiversity can threaten the economic and social well-being of these communities. Efforts to mitigate the impacts of climate change on marine biodiversity are crucial for preserving our oceans and the well-being of coastal communities (Shivanna, 2022).

Many marine species are threatened by the danger of extinction due to climate change. For example, Chinook salmon (Oncorhynchus tshawytscha), a pivotal species in North American riverine ecosystems, face grave threats from escalating sea surface temperatures and altered freshwater conditions, including heightened water temperatures and disrupted flow patterns. These changes have profoundly affected their life cycle, resulting in diminished survival rates (Crozier et al., 2021). The decline of Chinook salmon populations destabilizes the food web, impacting apex predators such as orcas and bears, and impairing nutrient cycling within aquatic ecosystems (NOAA Fisheries, 2021). This cascading effect highlights the indispensable role of Chinook salmon in sustaining ecological equilibrium (Crozier et al., 2021).

Fig. (18): Climate change is pushing Chinook salmon towards extinction by altering their freshwater habitats and life cycles. This decline disrupts food webs and nutrient cycling, underscoring the species' critical role in maintaining ecological balance. https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=920

Climate change is significantly increasing the extinction risks for whales and sharks, two crucial marine species. Whales, such as the North Pacific right whale (figure 19), are particularly vulnerable due to their reliance on zooplankton, which is affected by changing sea ice coverage and warming ocean temperatures (NOAA Fisheries, 2023). Similarly, sharks, including the oceanic whitetip shark, face habitat loss and prey scarcity as ocean temperatures rise and storm intensity increases, disrupting their migratory patterns and feeding behaviors (NOAA Fisheries, 2023). The decline of these apex predators destabilizes marine ecosystems, leading to imbalances in prey populations and nutrient cycling, both of which are vital for ocean health (NOAA Fisheries, 2023).

Fig. (19): Climate change is driving whales like the North Pacific right whale towards extinction by disrupting their food sources and habitats. This decline destabilizes marine ecosystems, highlighting the urgent need for conservation efforts https://media.greenpeace.org/archive/Humpback-Whale-in-the-Great-Barrier-Reef-27MDHUUL0O8.html

Green sea turtles (Chelonia mydas), essential to marine ecosystems, are increasingly threatened by climate change. Rising temperatures skew the sex ratio of hatchlings, with warmer sands producing predominantly female offspring (figure 20), thereby threatening future reproductive viability (Jensen et al., 2018). Additionally, rising sea levels and intensified storms erode nesting beaches, increasing their vulnerability (WWF, 2023). The decline of green sea turtles disrupts marine food webs and nutrient cycling, as they play a crucial role in maintaining healthy seagrass beds and coral reefs (WWF, 2023).

Fig. (20): Climate change threatens green sea turtles by skewing hatchling sex ratios and eroding nesting beaches, jeopardizing their future and disrupting marine ecosystems. https://www.4ocean.com/blogs/cause-of-the-month/cotm-green-sea-turtles.

5. Impacts on agriculture

Agriculture is highly vulnerable to climate change due to its large scale and sensitivity to weather conditions, resulting in significant economic repercussions (Mendelsohn et al., 2009). The global concern over the impact of climate change on agricultural production is considerable. Food security is a major issue, as human activities and ecosystem services are threatened by harmful human-induced climate interference (Watson et al., 2000; IPCC, 2001a, b; Ecosystem Millennium Assessment, 2005; see also Article II, UNFCCC). Countries are naturally concerned about the potential damages and benefits from climate change impacts on their territories and globally, as these will influence domestic and international policies, trade patterns, resource use, regional planning, and ultimately the welfare of their populations.

Changes in climatic events, such as temperature and rainfall, significantly affect crop yields. The effects of rising temperatures, precipitation variation, and CO2 fertilization vary based on the crop, location, and magnitude of change. Increased temperatures tend to reduce yields, while increased precipitation may offset or mitigate the impact of rising temperatures (Adams et al., 1998).

Fig. (21): The impacts of climate change on Agriculture relative to global warming, Extreme weather and rainfall intensity https://www.researchgate.net/figure/Potential-role-of-biochar-in-soil-amendments-and-crops-productivity-by-various_fig3_372526659.

Current research indicates that while crops might respond positively to elevated CO2 levels in the absence of climate change (e.g., Kimball et al., 2002; Jablonski et al., 2002; Ainsworth & Long, 2005), the combined effects of high temperatures, altered precipitation patterns, and possibly more frequent extreme events like droughts and floods are likely to reduce yields and increase production risks in many regions, exacerbating the disparity between rich and poor countries (e.g., IPCC, 2001a, b). There is a consensus that developing countries are more vulnerable to climate change than developed countries due to the predominance of agriculture in their economies, limited capital for adaptation, warmer baseline climates, and greater exposure to extreme events (Parry et al., 2001).

The impact of climate change on crop yields varies by region and irrigation practices. Expanding irrigated areas can increase crop yields but may harm the environment (Mahato, 2014). Rising temperatures are expected to reduce the yield of many crops by shortening their growing periods. The overall production of wheat, rice, and maize is projected to decrease if both temperate and tropical regions experience a 2°C warming (Challinor et al., 2014). Climate change generally has a greater impact on tropical regions, as tropical crops are closer to their high-temperature limits and thus experience more stress during elevated temperatures.

Additionally, insect pests and diseases are more prevalent in humid and warmer regions (Rosenzweig et al., 1992). Other factors such as humidity and wind speed, along with temperature and rainfall, also affect crop yields. Without considering these factors, there is a risk of overestimating the costs of climate change. Climate change is expected to reduce the yields of wheat, corn, and rice in China by 18.26 ± 12.13%, 45.10 ± 11.55%, and 36.25 ± 10.75% respectively by 2100 (Zhang et al., 2017). Extreme weather events have become more frequent since the 1900s in the Netherlands, significantly affecting wheat yields. The timing of these events determines the extent of yield reduction (Powell et al., 2016).

Projections indicate higher drought frequencies in the near future due to climate change, with the drought-affected area expected to increase from 15.4% to 44.0% by 2100. Africa is identified as the most vulnerable region, with major crop yields in drought-prone areas expected to decrease by over 50% by 2050 and nearly 90% by 2100 (Li et al., 2009). Plant-water relationships are highly sensitive to changes in temperature and precipitation, with extreme variations in these parameters having a greater impact on physiological changes than average climate changes (Reyer et al., 2012).

Fig. (22): Climate change alters land Fertility leading to decrease crops' yield leading to economic loss and starvation. https://eos.com/blog/climate-change-and-agriculture/.

Increased atmospheric CO_2 levels have been found to reduce plant transpiration, leading to a rise in air temperature by 0.42 ± 0.02 K. This indirect physiological effect, combined with the direct radiative effect, can increase land surface warming by 3.33 ± 0.03 K (Cao et al., 2010). While higher CO_2 levels are expected to boost crop yields, the developmental changes in plants depend on the crop type. C3 crops are expected to produce more, but the water requirements for both C3 and C4 crops are expected to decrease in non-stressful conditions. However, these benefits are likely to be offset by higher temperatures and altered precipitation patterns (Damatta et al., 2010).

Numerous studies indicate that climate change is causing increasing losses in crop productivity (Zhu et al., 2021). Besides affecting crop yields, climate change is also reported to reduce the nutritional value of food grains (Jagermeyr et al., 2021). For instance, higher atmospheric CO_2 levels decrease the protein, mineral, and vitamin content in rice (Zhu et al., 2018), which may also apply to other cereal crops. Given that rice provides 25% of global calories, this would significantly impact food and nutritional security in predominantly rice-growing countries.

Climate change is also expected to increase the prevalence of insect pests, further reducing crop yields. Floods and droughts significantly affect food production, and global warming impacts crop productivity through its effects on pollinators. Insect pollinators contribute to the production of 75% of the leading food crops (Rader et al., 2013). Climate change significantly reduces the density and diversity of pollinators (Shivanna et al., 2020). Under extreme temperatures, bees spend less time foraging (Heinrich, 1979), adding additional constraints to the pollination efficiency of crop species.

6. Impacts on Human Health

Climate change is increasingly recognized as a significant threat to human health, affecting various aspects of well-being and leading to higher mortality and morbidity. This report explores the direct and indirect health effects of climate change, supported by recent data and scientific findings.

6.1. Direct Health Impacts

Climate change directly impacts human health through extreme weather events such as heatwaves, storms, and floods. According to the World Health Organization (WHO), climate change is projected to cause approximately 250,000 additional deaths annually between 2030 and 2050 due to heat stress, undernutrition, malaria, and diarrhea (WHO, 2023). Heatwaves have been associated with increased mortality rates, particularly among vulnerable populations like the elderly and those with pre-existing health conditions (National Institute of Environmental Health Sciences, 2023).

6.2. Indirect Health Impacts

Indirectly, climate change alters the environment in ways that promote the spread of infectious diseases. Changes in temperature and precipitation patterns can expand the habitats of vectors such as mosquitoes, leading to increased transmission of diseases like malaria and dengue fever (USEPA, 2024). For example, warmer temperatures and increased rainfall can enhance mosquito breeding sites, facilitating the spread of these diseases (WHO, 2023).

6.3. Respiratory and Cardiovascular Diseases

Climate change also worsens air pollution, which is linked to respiratory and cardiovascular diseases. Increased levels of ground-level ozone and particulate matter can lead to conditions such as asthma, bronchitis, and heart disease (USEPA, 2024). The WHO estimates that air pollution contributes to approximately 7 million deaths annually, with climate change expected to exacerbate this issue (WHO, 2023).

6.4. Water and Food Security

Changes in climate can disrupt food and water supplies, leading to malnutrition and waterborne diseases. Floods and droughts can contaminate water sources, raising the risk of diseases like cholera and other diarrheal illnesses (National Institute of Environmental Health Sciences, 2023). Additionally, climate change can impact crop yields, resulting in food shortages and undernutrition, especially in vulnerable regions (WHO, 2023).

6.5. Mental Health

The psychological impacts of climate change are substantial. Extreme weather events and the resulting displacement and loss can lead to mental health issues such as anxiety, depression, and post-traumatic stress disorder (PTSD) (USEPA, 2024). Hurricane Katrina in 2005 has been linked to acute stress, PTSD, and higher rates of depression and suicide in affected communities (Boscarino et al., 2014). These mental health consequences are particularly concerning for people facing recurring disasters, posing a cumulative psychological toll. Following exposure to Hurricane Katrina, veterans with preexisting mental illness had a 6.8 times greater risk of developing additional mental illnesses compared to veterans without preexisting conditions. Increased levels of PTSD have also been reported among individuals who perceive their community members as less supportive following hurricanes (Ursano et al., 2014). The stress of dealing with the aftermath of disasters and the uncertainty about future climate conditions can exacerbate these mental health challenges (National Institute of Environmental Health Sciences, 2023).

7. Interpretation

7.1. Mitigating Climate Change Impacts on Biodiversity, Agriculture, and Human Health

According to Suh (2006), producing a dollar's worth of goods or services in the USA emits, on average, 0.36 kg of CO_2 into the atmosphere. Economic growth thus significantly drives increased greenhouse gas (GHG) emissions. Wilting et al. (2017) further emphasized that GHG emissions associated with the production and consumption of goods and services contribute to biodiversity loss.

7.2. Mitigation Strategies

Mitigation focuses on reducing the sources of greenhouse gases and enhancing the sinks that absorb these gases. Key strategies include:

1. Transition to Renewable Energy: Replacing fossil fuels with renewable energy sources such as solar, wind, and hydroelectric power is crucial. This transition can significantly reduce carbon emissions (MIT Climate Portal, n.d.). Associate Professor Jingjie Wu and his team discovered that a modified copper catalyst improves the electrochemical conversion of carbon dioxide into ethylene, a key ingredient in plastic and many other products. This innovation not only reduces atmospheric CO_2 but also produces ethylene, one of the world's most important chemicals, used in everything from textiles to antifreeze to vinyl.

2. Energy Efficiency: Improving energy efficiency in buildings, transportation, and industries can lower energy consumption and emissions. This includes better insulation, energy-efficient appliances, and electric vehicles (NOAA Climate.gov, 2020).

3. Carbon Capture and Storage (CCS): CCS technologies capture carbon dioxide emissions from sources like power plants and store them underground, preventing CO_2 from entering the atmosphere (Moustafa & Ghowail, 2022).

4. Reforestation and Afforestation: Planting trees and restoring forests enhance carbon sinks, absorbing CO_2 from the atmosphere. Protecting existing forests from deforestation is equally important (MIT Climate Portal, n.d.).

5. Sustainable Agriculture: Adopting sustainable farming practices, such as reduced tillage, crop rotation, and organic farming, can lower emissions from agriculture. Reducing food waste and shifting to plant-based diets also contribute to mitigation (Fawzy et al., 2020).

7.3. Adaptation Strategies

Adaptation involves adjusting to the current and future impacts of climate change. Key strategies include:

1. Infrastructure Resilience: Building and retrofitting infrastructure to withstand extreme weather events, such as floods and hurricanes, is essential. This includes improved

storm drainage systems and flood barriers (MIT Climate Portal, n.d.).

2. Water Management: Efficient water management practices, such as rainwater harvesting and desalination, can address water scarcity issues exacerbated by climate change (MIT Climate Portal, n.d.).

3. Agricultural Adaptation: Developing climate-resilient crops and diversifying agricultural practices can help maintain food security. This includes breeding drought-resistant crops and implementing efficient irrigation systems (MIT Climate Portal, n.d.).

4. Ecosystem Restoration: Restoring wetlands, mangroves, and other natural buffers can protect coastal areas from storm surges and erosion. These ecosystems also provide critical habitats for biodiversity (MIT Climate Portal, n.d.).

5. Community Preparedness: Educating and preparing communities for climate-related disasters can reduce vulnerability. This includes early warning systems, emergency response plans, and public awareness campaigns (MIT Climate Portal, n.d.).

The Intergovernmental Panel on Climate Change (IPCC) emphasizes the need for immediate and deep emissions reductions to limit global warming to 1.5°C above pre-industrial levels. Emissions must peak by 2025 and be reduced by 43% by 2030 to avoid the most severe impacts (World Economic Forum, 2023). By implementing these strategies, we can mitigate the impacts of climate change on biodiversity, agriculture, and human health, ensuring a more sustainable future for all.

Mitigating climate change impacts necessitates a multifaceted approach, combining mitigation and adaptation strategies. By transitioning to renewable energy, enhancing energy efficiency, and implementing sustainable practices, we can reduce greenhouse gas emissions. Simultaneously, building resilient infrastructure and preparing communities for climate-related challenges will help us adapt to the changes already underway. Urgent and collective action is essential to secure a sustainable and livable future for all.

8. Expectations for the climate change crisis

The future of our planet hinges on the actions taken by the current generation to address the climate change crisis. If immediate and substantial measures are not implemented, the impacts on biodiversity, agriculture, and human health will be catastrophic. Biodiversity is already under severe threat, with many species unable to adapt to rapidly changing temperatures and habitats, leading to mass extinctions (IPCC, 2022). Agriculture, a critical sector for global food security, faces unprecedented challenges from altered precipitation patterns, increased frequency of extreme weather events, and the proliferation of pests and diseases (FAO, 2018). Human health is equally at risk, with rising temperatures exacerbating heat-related illnesses, expanding the range of vector-borne diseases, and increasing the frequency of extreme weather events that cause injuries and fatalities (WHO, 2021). Despite the clear and present dangers, the actions taken by countries worldwide remain insufficient to mitigate the crisis effectively. The Paris Agreement, while a significant step, has not yet resulted in the necessary reductions in greenhouse gas emissions (UNFCCC, 2015). Without a dramatic escalation in efforts, the window of opportunity to prevent irreversible damage is closing rapidly. The current generation is the last hope to implement transformative changes; failure to do so will result in a future marked by severe ecological, agricultural, and health crises that will be impossible to reverse (IPCC, 2022).

Conclusion

In conclusion, climate change, defined as long-term alterations in temperature and weather patterns, primarily due to human activities, has led to a series of catastrophic disasters. These include more frequent and severe storms, droughts, and heatwaves, which have profound impacts on biodiversity, agriculture, and human health. Biodiversity is significantly threatened by climate change, with both marine and terrestrial species facing unprecedented risks. For instance, coral reefs are experiencing bleaching events, while polar bears are losing their ice habitats. Terrestrial species like the Bengal tiger and the monarch butterfly are also at risk of extinction due to habitat loss and changing climatic conditions. Agriculture is another sector severely affected by climate change. Rising temperatures and altered precipitation patterns have led to reduced crop yields and increased pest infestations. Staple crops such as wheat, rice, and maize are particularly vulnerable, threatening global food security and the livelihoods of millions of farmers. Human health is directly and indirectly impacted by climate change. Increased temperatures contribute to the spread of vector-borne diseases like malaria and dengue fever. Additionally, extreme weather events can lead to injuries, fatalities, and mental health issues. Vulnerable populations, including the elderly and those in low-income regions, are disproportionately affected.

Mitigation strategies are essential to address these impacts. Transitioning to renewable energy sources, improving energy efficiency, and implementing carbon capture and storage technologies are critical steps. Reforestation, sustainable agricultural practices, and community preparedness can also play significant roles in reducing greenhouse gas emissions and enhancing resilience. Immediate and coordinated global action is necessary to mitigate the adverse effects of climate change. By adopting these strategies, we can protect biodiversity, ensure food security, and safeguard human health, paving the way for a sustainable future.

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