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Environment and climate change: Influence on biodiversity, present scenario, and future prospect

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ABSTRACT

Climate change has become a widespread problem in recent years. It is one of the most important global environmental challenges affecting all the natural ecosystems of the world. Various parameters such as increased CO_2 levels, faster glacier melts, and rainfall variability and severe drought have been associated with climate change. Biodiversity is influenced by climate change in different ways including shifts in ranges, changes in relative abundance within species ranges, and subtler changes in activity timing and microhabitat use. Soil properties and water resources are affected by fast changing climate. All these consequences demand for integrated management approaches, proper planning and designing policies to safeguard the biodiversity and hence environment. The present review describes the effect of changing climate on prokaryotic and eukaryotic communities, environment, and economics, the response of communities to such changes and conservation strategies that could be adopted to respond to these changes.

ARTICLE HIGHLIGHTS

- Changing climate is a global challenge
- It is affecting prokaryotic and eukaryotic biodiversity, environment, and economics
- Conservation and mitigation strategies are of global importance
- Framing policies is important to safeguard biodiversity and environment in present scenario of climate change crisis

1. INTRODUCTION

The super challenges of the 21st century are climate change, energy supply, health and disease invasion, and sustainable environment. The world's climate continues to change at a rate expected to be unprecedented in recent human history. The increase of about 0.6°C in global average surface temperature has been observed during the twentieth-century. In recent years, human activity and natural factors have led to rapid increase in greenhouse gas (GHG) emissions. The influence of emitted GHG on future climate is estimated due to its capability of absorbing available infrared radiation and its persistence in the atmosphere [1]. The effects of global warming are broader which may include arctic shrinkage, glacial retreat, and worldwide sea level rise. The changing precipitation patterns will result in more floods and drought. The changes will also occur in agricultural yields, there may be addition of new trade routes, vast extinction of species and increase in disease vectors range [2].

In fact, the climate change is not only an environmental issue nor is it the only threat to global prosperity rather is a threat multiplier for diverse other urgent concerns including global security, disease and habitat loss. Climate change is unique in its scale and enormous risks it poses. Climate change, if remained unchecked, possibly will redraw the map of the planet. It can create global living conditions beyond

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the range, humanity has ever experienced in history. The influence of climatic change is much broader, such as increased frequency of hypoxic events, storm activity, altered rainfall patterns, and flow regimes of freshwater streams and rivers [3]. There is a discernible global pattern of the effects of climate change on crop productivity, which may have implications for food availability. Climate change may jeopardize the stability of entire food systems. The demand for agricultural products has been estimated to increase with increase in global population, which may require a shift toward sustainable intensification of food systems [4].

Rising concentration of atmospheric carbon dioxide is one of the most critical problems as its effects are globally persistent and irreversible on ecological timescales [5]. The primary direct consequences are increasing ocean temperatures [6]. Rising temperatures create additional changes such as increase in ocean stratification, increasing sea levels, reduced sea ice extent, altered ocean circulation patterns, precipitation and freshwater inflows. Acidification is another direct impact of rising CO_2 concentrations on oceans [7]. Climate change also affects global biodiversity in several ways. Movement is an integral part of ecology of many animals, which can affect the fitness of individuals and population survival by enabling foraging and predation, behavioral interactions, and migration [8]. Migration may also be observed in fishes in search of suitable conditions due to increase in temperature. Arrival and hatching date in migrating birds can be strongly affected by global warming [9]. Numerous changes occur in animals due to rising temperature such as increased respiration, decrease in the efficiency of nutrient utilization, decrease in milk production reproductive performance especially in dairy cows [10]. Climate is a major factor determining plant physiology, distribution, and interactions [11]. There might be changes in phenological phases of plants which will lead to prolonged growing season and affect the plant fitness. Evidences are in favor of global climate change and its consequences on different aspects of environment. There is a greater need to develop conservation strategies to respond to such global challenges. This review deals with the influence of climate change on biodiversity and impact on environment.

2. IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Climate change is increasingly recognized as the serious and widespread threat to biodiversity. The alterations in the environment which will be brought up by the climatic changes will be too rapid for many species to adapt to, and ultimately lead to extensive extinctions. Climate change may lead to migrations which in turn will affect biological diversity at regional and global scales. Stress on populations of whales, ringed seals, and polar bear will continue as a result of changes in critical sea-ice habitat interactions. Crops will fail more often, especially on land at lower latitudes where food supply is scarce [12]. The changes in occurrence of drought, strong winds, and winter storms will bring massive loss to commercial forestry [13]. The species must adapt, move, or face extinction with climate change.

2.1. Animal Biodiversity

Animals had been already subjected to major shifts in the Earth's climate in the past. Some species perished, while others adapted and thrived. Climate change is already having a negative impact on animal life, and the consequences are likely to be disastrous in the future. Climate change is considered a major threat to the survival of many species in changing ecosystems [14-16]. Many studies have taken into account the economic impact of day by day changing climate on livestock production [17]. In general, a combination of rising temperatures and changing rainfall patterns will certainly affect animal husbandry. Feed is an important constraint for livestock production in the tropics, and will continue to be, and crop productivity is a useful proxy for feed availability in most regions. Crop productivity at mid-to high latitudes may increase slightly for local mean temperature increases while at the lower latitudes, it may decrease for even relatively small local temperature increases. In general climate change may affect the animal agriculture in different ways by influencing livestock [18], nammely, the availability and price of feed grain, quality, and production of forage, reproduction, growth and health, as well as distribution of diseases and pests. These changes can lead to redistribution of livestock in an area. There may be shifts in animal types used for instance change from cattle to buffalo, camels, goats, or sheep; there may be genotype shifts which mean the use of breeds which can well handle adverse conditions. Furthermore, there may be changes in housing of animals [17].

Temperature is likely to become hotter in several places and different species due to their physiological differences will show variations in their susceptibility to changing temperatures [19]. Holstein-Friesian dairy cows are primarily susceptible to heat stress as the ambient temperature exceeds 25°C [20]. The first sign of heat stress is an increase in body temperature and rate of respiration ultimately reducing feed intake and milk output [21,22]. Sheep when exposed to high temperatures, weight loss, decrease of average daily gain, growth rate, and total body solids reflected by impaired reproduction have been observed. When the ambient air temperature is high, appetite decreases and growth of pigs is affected [23]. Further, in such changes, some species of animals may expand their ranges whereas others may move towards the poles or upward in elevation. An example of such a shift is population of red fox in Canada which have been advancing north and, on the other hand, population of Arctic fox has been retreating [24]. High temperatures and precipitation have been known to decline the population of British ring ouzel which is a shy species of thrush with a high chirping call.

The decline in Arctic sea ice have a significant impact on Arctic vertebrate populations including polar bears, seals, and walruses which are adapted to live in sea ice for significant periods of the year [25]. If the sea ice breaks and drifts as a result of polar warming, polar bears will have to move north to find a stable platform. Pregnant females will leave the ice to find their preferred land den area have to swim long distances. In case, the pregnancy of malnourished mothers is successful under sub-optimal habitats, the chances of survival of cubs will be greatly reduced [26].

Climate change has a profound impact on the oceans. The upper ocean is warming [27], potentially affecting invertebrate populations including krill, which are important food sources for whales, seabirds, seals, and penguins [28]. Changes in upper ocean temperatures may alter the range of many species, especially marine mammals. Studies show the expansion in the range of common dolphins common in northwest Scotland which are warmer water species whereas contractions in the range of white-beaked dolphins which are a colder water species [29]. Relatively small changes in temperature alter the metabolism and physiology of fishes, affecting their growth, reproduction, feeding behavior, distribution, migration, and abundance [30].

2.2. Bird Biodiversity

Birds are one of the most studied organisms on the planet, and they serve as an important group of indicators for learning about the effects of climate change. The choice of birds for studying climatic changes offer certain advantages such as they are the most well-known kind of organism for climate studies and second, millions of citizen scientists track birds all over the world, contributing to massive datasets [31]. Bird distribution changes have been well described and linked to climate change [32-34]. The vulnerability of species of tropical birds to climate change in particular has been increasingly recognized [35-37]. The weather not only affects the metabolic rate of the birds (e.g., in cold weather where energy expenditure must increase to maintain the body), but also their behavior directly or indirectly [38]. Climate change has been shown to impact breeding. Extreme weather events, such as prolonged freezing spells and droughts, can have catastrophic effects on bird populations, including long-term effects on entire cohorts [39]. The study of Pied Flycatchers *Ficedula hypoleuca* showed increase in their egg size with warmer springs in Germany and Finland [40]. In Siberia, reproductive success in the planktivorous auklets including crested *Aethia cristatella* and parakeet *Cyclorhynchus psittacula* increases at lower sea-surface temperatures. On the other hand, better reproductive success has been observed in the piscivorous puffins such as horned *Fratercula corniculata* and tufted *Lunda cirrhata* at higher, sea-surface temperatures. Long-term changes in sea-surface temperatures can affect the viability of each species' population in different ways and change the seabird population in that area [41].

Storms and snowpack have a significant impact on the reproductive schedules of birds breeding at high altitudes. Climate change is expected to have an impact on reproduction as well as the entire annual cycle of birds. The species that mainly adjust the annual cycle and multiply according to rainfall, temperature, and food supply will face fewer difficulties as compared to those that coordinate their annual cycle by a rigid Zeitgeber, like photoperiod [42]. Migration in birds is affected by changes in climatic conditions. It is expected that the greater the distance of migration of the species, the more likely one or more aspects of the annual cycle may become mistimed with local weather and food supplies on the summering grounds. An advancement of 14 days over 47 years in the timing of egg laying in *Parus major* population in the United Kingdom due to increased spring temperature has been reported [43].

2.3. Plant Biodiversity

Climate change is also affecting the life cycles and distributions of the world's vegetation. The combination of the changes in air quality and composition and climate are producing new bioclimate for food production systems. There is extensive evidence that plant seasonal biological events have changed in recent decades along with the global climate change [44]. Some medicinal and aromatic plants have begun to flower earlier. In Britain, the first flowering date for approximately 385 plant species advanced by 4.5 days on average over the previous four decades [45]. Temperature range between 45°C and 65°C can cause severe damage and even death of crop plants. For instance, rice is most sensitive to temperature change at anthesis stage. Exposure for few hours at flowering can reduce floral reproduction [46].

In medicinal plants, the damaging effects of climate change may include decrease in availability and most dramatically in the extinction of species [47]. A study reported extinction of about 600 plant species in the past 250 years [48].Valuable medicinal plants are likewise one of those species that experience dramatic phenological change [49]. In addition to endangering population growth, phenological changes may have an impact on the predictable or consistent availability of medicines to those who rely on them [50,51]. The medicinal plants of arid zone may also be at special risk. The nival or subnival species in montane ecosystems are most vulnerable to habitat loss [52], and future climate change is expected to be most severe in northern latitude mountains [53]. Alpine meadows are once again among the most threatened plant communities [54], and they are shrinking due to warming-induced upslope shrub encroachment [55]. It is thought that species growing at the highest altitudes are most vulnerable to extinction because they will have nowhere to go if they are outcompeted by lower elevation species that are now expanding their ranges to higher elevations [56].

In a survey of plant distribution in Arizona mountains local extinction of 15 species of plants including *Muhlenbergia porter, Quercus gambelii* and *Urochloa arizonica*, in comparison with 50 years earlier has been observed [57]. In the alpine Himalayas of Sikkim 75 species of plants, including *Rhododendron nivale*, *Potentilla fruticosa* and *Lepidium capitatum* were observed to be locally extinct in comparison with 1850 [58].

Deserts and arid shrublands are expected to experience the fastest rates of climate change, making compensatory migration difficult [59]. For instance, a significant degradation has been observed in the desert steppe habitat of one of the most widely used wild medicinal plants *Glycyrrhiza uralensis*, attributed to increasing climate change and anthropogenic disturbance [60]. Sea grasses are declining globally at a rate of about 7% per year, and global climate change is expected to have a negative impact on them, posing a pressing challenge for coastal management [61]. Water temperature greatly influences the physiology, growth rates and reproduction in sea grasses and determines their geographic distribution based on their temperature tolerance [62]. The species of tropical sea grasses including *Thalassia testudinu*m and *Syringodium filiforme* in the Gulf of Mexico showed reduction in their productivity when summer temperatures were higher [63]. In an investigation in Australia, the leaf growth rates of *Thalassia hemprichii, Halodule uninervis,* and *Cymodocea rotundata* were reduced at water temperature above 40°C [64].

Warming is occurring quickly in the Arctic [65]. The fluctuations in ranges of temperature and changes in ice covers and snow patterns are affecting the distribution of Arctic vegetation. It has been observed that the changes in climate possibly will affect the chemical constituents and thus the survival of the aromatic and medicinal plants in Arctic. Certain reports have revealed the impact of the temperature fluctuations on bioactive compounds of the plants [66,67].

2.4. Microbial Biodiversity

Microbes inhabiting soil play significant roles in nutrient cycling and protecting plants from environmental stresses [68]. The organisms inhabiting the soil interact with each other and plants in many ways that shape and maintain the ecosystem. Climate change is altering the distribution and diversity of species and at the same time affecting the interactions between organisms [69,70]. Numerous studies have shown that changes in species interactions in response to climate change chain alter biodiversity and function of terrestrial ecosystems [24,71]. There are some reports on soil microbial communities (SMCs) and their diversity and distribution during climatic change [72,73]. Alterations in relative abundance and function of soil communities due to climatic changes has been observed as the members of SMCs vary in their physiology, temperature sensitivity, and growth rates [74,75]. A study observed changes in the relative abundances of soil bacteria and increased the bacterial to fungal ratio of the community due to warming by 5°C [76]. Further, the acceleration in fermentation, methanogenesis and respiration among the microbial communities has also been observed in response to increase in temperature. The microbial community composition (MCCs) of soil constantly changes as they respond to changing resource availability. Certain communities grow quickly and utilize the resources as they are available and some communities adapt and grow slowly and utilize more chemically complex substrates. Guo *et al*. [77] carried out study on climate warming accelerates temporal scaling of grassland soil microbial biodiversity. The study suggested that the strategies of soil biodiversity preservation and ecosystem management may need to be adjusted in a warmer world. The study of Wu *et al*. [78] concluded detrimental effects of biodiversity loss might be more severe in a warmer world. Recently, a study has been conducted to measure the effect of climate change in Antarctic microbial communities. The study proposed that climate change studies in Antarctica should consider descriptive studies, short-term temporary adaptation studies, and long-term adaptive evolution studies and concluded that this will help in understanding and managing the effects of climate change on the Earth [79].

A study investigated the effect of temperature on microbes in dry land soil, boreal, temperate, and tropical soil and response of microbial communities to different temperatures. The study concluded that the rates of respiration per unit biomass were lower in the soils collected from the environments having higher temperature and suggested that thermal adaptation of the microbial communities may lessen positive climate feedbacks [80]. Another study reported increased soil biomass and fungal abundance with higher atmospheric CO_2. The study showed a limited effect on bacterial diversity with higher atmospheric CO_2 [81]. Drought conditions have been shown to influence fungi and bacteria, but fungi are known to be more sensitive than bacteria. It has been observed that during drought fungal growth increases [82].

Another study observed the effects of elevated levels of CO_2 and precipitation on soil microorganisms. The study suggested that bacterial growth was negatively affected whereas fungal biomass was observed to show an increase with increasing precipitation [83]. On the other hand, it has been suggested that global warming increases the abundance of bacteria and fungi and leads to the alteration of the soil food web. The rise in temperature also makes changes in the physiology of decomposing microorganisms also [84]. Climate change is known to favor the growth of cyanobacteria [85]. Many bloom-forming cyanobacteria grow at high temperatures [86]. The growth of *Microcystis* sp. has been observed to increase at elevated CO_2 levels [87]. Generally as the environmental conditions change, the resident microbial communities either adapt, become dormant or die [88].

3. BIODIVERSITY RESPONSES TO CLIMATE CHANGE

Climate change is expected to change the diversity of species, the distribution of human pathogens, and ecosystem services around the world. Estimating these changes and designing suitable management strategies for future ecosystem services will need a predictive model that includes the most basic biological responses. One of the key questions in the debate over climate change's ecological impact is whether species can adapt quickly enough to keep up with the rapid pace of climate change [89,90]. Species can, in theory, change in response to climate change, and changes have already been observed. The species can track and follow suitable conditions in space, which is typically accomplished through dispersion. Spatial movement of species tracking appropriate climatic conditions on a regional scale is the best documented response from palaeontological records and recent observations. Over 1000 species of marine invertebrates, insects, and birds have already shown latitudinal and altitudinal range shifts [91], resulting in a decrease in range size, primarily in mountain top and polar species [92]. Furthermore, in order to keep up with abiotic factors that represent cyclic variation, such as on a daily or yearly basis, species may respond to changes by shifting time from daily to seasonal. A meta-analysis of a wide range of plant and animal species found that the average response to climate change was a shift in key phenological events occurring 5.1 days earlier per decade over the last 50 years [93]. The advancement in flowering by more than 10 days per decade has also been observed in some species [91]. Another approach is species may adapt themselves to the changing climate in their local range. Thus, there are multiple responses of the species to cope up with the changing climatic conditions and unable to adapt to new conditions, the species may go extinct either locally or globally [94].

4. GLOBAL BIODIVERSITY SCENARIO FOR THE YEAR 2100

As a result of numerous human-caused changes in the global environment, global biodiversity is changing at an unprecedented rate [95,96]. Quantitative scenarios are emerging as tools to assess the impact of future socio-economic development pathways on biodiversity and ecosystem services. Global marine, freshwater, and terrestrial biodiversity scenarios are analyzed through different measures including change in the abundance of the species, habitat loss, extinction, and distribution shifts [97]. The risk of species extinction address the irreversible component of biodiversity change [98,99]; however, species extinctions have weak links to ecosystem services and respond less rapidly to global change than other factors. Quantitative global extinction scenarios for freshwater and marine organisms are, however, uncommon. According to one of the proposed models based on the relationship between fish diversity and river discharge, 4–22% extinction of fish by 2070 in about 30% of the world rivers, due to reduced river discharge from climate change and increased water withdrawals [100]. Habitat loss and degradation in terrestrial ecosystems encompass a wide range of human-caused changes in natural and semi-natural ecosystems. The distribution shifts are expected to cause the reorganization of ecosystems, including the establishment of novel communities [96]. Scenarios constantly indicate the decline of the biodiversity over the 21st century. The most important factors identified so far to induce changes in biodiversity at global scale includes the changes in the concentration of carbon dioxide, land use, deposition of nitrogen, and on purpose or accidental introduction of alien animals, plants, and microbes in an ecosystem [101].

5. CONSERVATION OF BIODIVERSITY IN CHANGING CLIMATE

The changing temperature and precipitation patterns are expected to interact with other drivers to influence an array of biological processes and distribution of species. Alarming predictions about the potential consequences of future climate change are prompting policy responses ranging from the local to the global [102]. To date emission of greenhouse gases are driving earth to significant climate change in the coming decades [103]. The annihilation of evolutionary potential, possible loss of biodiversity and disturbance of ecological services must be taken seriously. Many countries have conservation plans for threatened species, but these plans have generally been developed without taking into account the potential impacts of climate change. Climate change is greatly influencing the biodiversity and represents a significant future challenge for biodiversity conservation strategies [94].The interaction between climate and land use provides opportunities for adaptation to climate change that increase the ability of species to adapt [104]. Preventing detrimental consequences for biodiversity requires immediate action and strategic conservation plans for years and decades to come [105]. Integration of different approaches and perspectives is required for more accurate information on which species and habitats, which places and how conservation managers can make the most of natural systems' adaptive capacity. In many cases, existing conservation policies and practices are already encouraging measures to reduce vulnerability to climate change such as restoration or creation that improves the functional connectivity of landscapes and habitat management. The assessment of impact of climate change on biodiversity has been especially based on empirical niche models [106]. These models for most species indicate large geographic displacements and widespread extinction. Assessing the biodiversity consequences of climate change is really a multifaceted issue and all aspects of vulnerability such as adaptive capacity, exposure, and sensitivity must be considered for implementation of conservation strategies [Figure 1] [107].

6. IMPACT OF CLIMATE CHANGE ON ENVIRONMENT

In recent years, extensive efforts have been made to monitor and predict climate change in response to fears of global warming. Attention has been focused on the diverse environments including soil and water, and the imminent socio-economic and environmental consequences of rising global temperatures. The fluctuations in temperature will leave a negative impact on organic matter of soil, and diverse physical and chemical properties of soil. Water resources will be greatly affected under changing climate [Figures 2 and 3].

6.1. Soil Health and Fertility

Healthy soil is the foundation of agriculture and a basic resource for meeting human needs in the twenty-first century. It is a critical component of ecosystems and earth system functions that helps to deliver primary ecosystem services [108]. The most recent report of the intergovernmental panel on climate change point outs the average rise in the global temperature between 1.1 and 6.4°C by 2090–2099. The changes in the climate will have impact on precipitation patters at global level and will alter both the amount of precipitation received and the distribution of precipitation over the course of an average year in many locations [109]. Each of these factors will affect soil which is of major importance for the food security [110-112]. Food security will be threatened through its effects on soil processes and different properties [113].

Soil moisture is another important component of the hydrological cycle that regulates precipitation partitioning between runoff, evapotranspiration, and deep infiltration [114]. Fluctuations in temperature will influence moisture content of the soil which in turn may impact infiltration and runoff amounts and rates [115]. Further, as a link between the biosphere and the edaphic zone, soil water is fundamental requirement for the terrestrial ecosystems which determines plant growth. Water stress occurs when the soil water level falls below a critical species-specific threshold, which will then lead to morphological and physiological disturbances in plants [116].

Soil erosion is another phenomenon experienced in different parts of the world under changing climate. It is one of the major threats to the economy and society affecting agriculture. The most common reason predicted for soil erosion is the change in the erosive power of rainfall and changes in plant biomass [117]. Although soil erosion is a natural and inevitable process, the accelerated rates of soil loss, is really a serious environmental issue. The

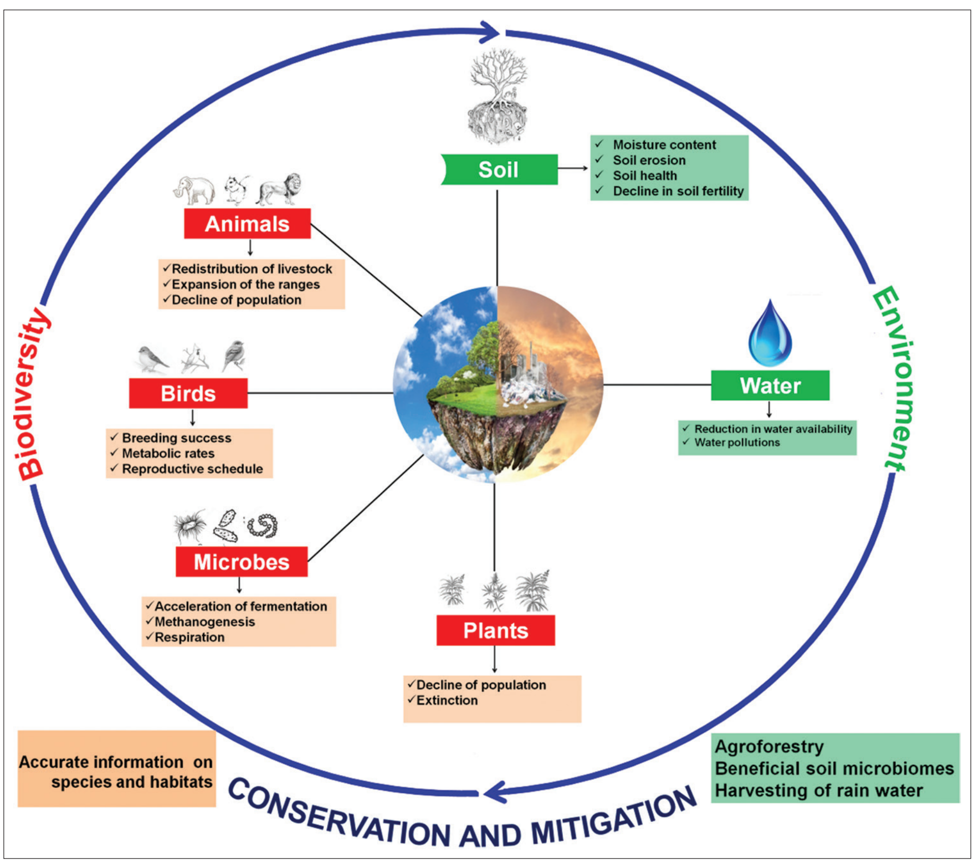

Figure 1: Depicts the effect of climate change on biodiversity and environment and their conservation/mitigation strategies.

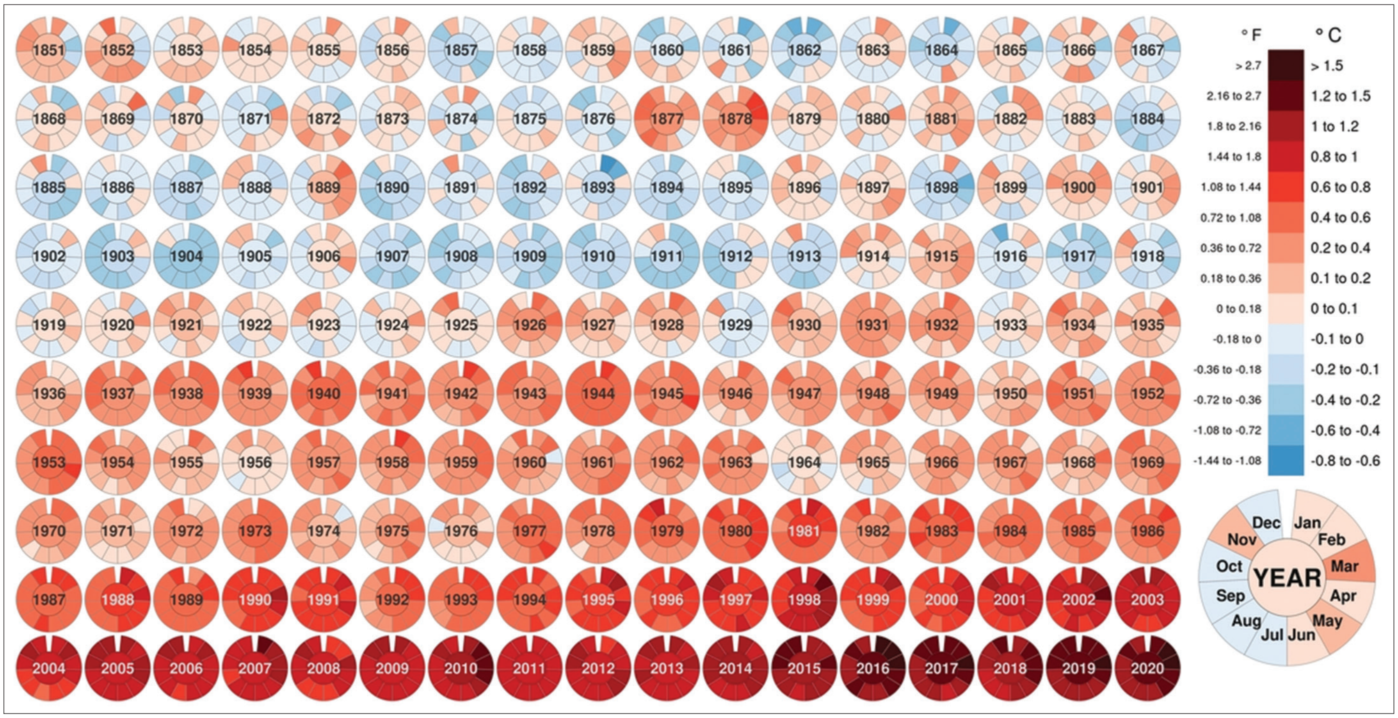

Figure 2: The changes in monthly mean global temperature from 1851 to 2020 (Data HadCRUT5 created by: @neilrkaye).

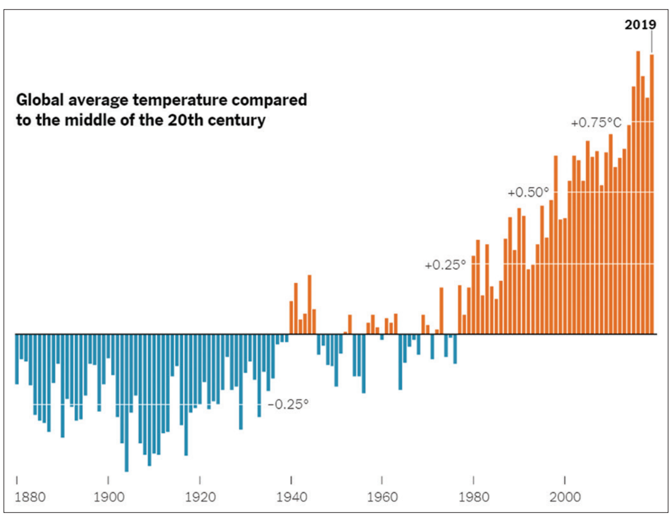

Figure 3: The changes in global average temperature from 1880 to 2019.

increased rates of soil erosion lead to nutrient loss, which affects agricultural productivity [118,119] and cause eutrophication of water bodies' [120]. Advanced stages of soil erosion, such as rill and gully erosion, can devastate entire areas, rendering them unfit for agricultural use [121,122]. Soil erosion is expected to increase with climate change and is the major problem that reduces the useful storage capacity of river dam reservoirs [123]. A study has been conducted to investigate the impact of climate change on soil erosion, runoff, and wheat productivity in central Oklahoma. The study concluded that no-till and conservation tillage systems will be effective in combating soil erosion under projected climates in central Oklahoma [124].

Soil fertility and productivity declines are common in tropical and subtropical areas of Asia, South America, and Africa, where soil loss due to erosion is estimated to be 30–40 t/ha/year [125,126]. Microorganisms present in the soil play important role in nutrient cycling and thus the decrease in MCCs in soil due to climate change affect the soil health and fertility.

Increasing challenges and concerns on global warming and changing climate have led to special attention to soil and its capability in carbon sequestration. In a study, the effect of climate change on soil organic carbon storage using the Rothamsted C model in the agricultural lands of Golestan province has been studied. The results suggested that with increasing temperature, the rate of decomposition of soil organic carbon will increase [127]. Soil organic carbon is an important carbon pool which can alleviate the increasing concentration of atmospheric carbon dioxide as part of the carbon cycling process. A study on the basis of Rothamsted C model concluded soil organic carbon will in general decline during the next decades. Further the rate of decrease of soil organic carbon will be higher over time if there is no addition of organic matter is adopted in China [128].

Another study focused on impact of global climate change on terrestrial soil CH_4 emissions. The meta-analysis in the study suggested that future climate change will decline the natural buffering capability of terrestrial ecosystems on CH_4 fluxes [129].

6.2. Water Resources

Climate change is expected to pose negative impact on water resources and freshwater ecosystems in almost every part of the world. However, the intensity and characteristics of the impact can vary widely from region to region. There may be water shortages in some regions. A study concluded that climate change will lead to water scarcity to meet the rising demand for food. It is estimated to be 60% higher in Africa by 2030, which will spike food prices and worsen food scarcity [130]. The shorter rainy periods and seasonality shifts might affect water resources by reducing water availability with wide ranging consequences for local societies and ecosystems [131].

With the increasing demand, large population will be at risk of water scarcity. The rise in sea level in coastal regions possibly will threaten the livelihood and lives of millions of people. The occurrence of droughts and floods is likely to increase in many parts of the world. All these factors will contribute to high economic cost and decline in the yield ultimately leading to higher risk of hunger and poverty [132].

A study has been conducted to analyze the impact of climate change on stream flow in the Godavari basin simulated using a conceptual model including CMIP6 dataset. The findings highlighted the importance of taking into consideration the potential impacts of future scenarios on water resources so that effective and sustainable water management practices could be developed [133]. Another study investigated the impact of the climate and land-use changes on water balance in 2037, the end of the National Strategy, for the Mun River Basin, NE Thailand. The study recommended soil-water conservation measures to alleviate the adverse effects of bioenergy [134]. The changing climate will also impact the water quality of lakes. A study has been conducted to investigate the effects of climate change on the water quality of Baiyangdian Lake in the past 30 years using correlation analysis, regression analysis, and the generalized additive model. The major conclusions of the study were the increment in the oxygen demand of organic matter in the lake due to rising temperature, increased total phosphorus in the lake due to increased precipitation and altered nitrogen and dissolved oxygen concentration in lake [135].

It is very important for water resources managers to be aware of the impact the climate change will have on hydrological cycle and flow regime and be prepared to find the strategies to cope with it. The better understanding on the link between the change in climate, water resources and the anthropogenic activities will help the water resource managers to make more rational decisions on the allocation and management of the water resources [136]. Social and environmental aspects including agriculture, biodiversity conservation, and tourism are connected to quality and availability of water resources, and consequently adaptation measures will be strongly bound with policies in a wide spectrum of disciplines [137].

7. CONSERVATION OF SOIL HEALTH, FERTILITY, AND WATER RESOURCES IN CHANGING CLIMATE

Soil and water are fundamental and basic necessities. The negative impact of changing climate on these basic resources is major global issue and developing strategies for their conservation is of utmost importance. The major research priorities of current studies are growing more food, conservation of the environment and reduction of global warming. Despite of changes in hydrology, climate, and increasing demand of agricultural commodities, there is a greater need to look further than the traditional approaches of the last century and embracing an expanded view of water and soil conservation to maintain an environmentally sound and sustainable landscape. Most importantly the new strategies must be based on far more effective policies and programs [138]. Agroforestry is one of the emerging technologies for water and soil conservation. It consists of a broad range of the practices including managing and establishing trees purposely around or within croplands, farm animal grounds, and pasture lands with the rationale of managing soil erosion, improving wildlife habitat, developing sustainable agricultural practices, ameliorating the effects of environmental pollution, and also adding to farm economy by harvesting tree based specialty products [139]. Conservation agriculture, another important approach for conservation of soil and water takes into account the conservation of biodiversity, labor and natural resources. It decreases drought stress, raises available soil water and maintains the soil health for a longer term. The strategy is practiced in Argentina, Australia, Brazil, Canada, New Zealand, Paraguay, and USA [140]. Further, it is also becoming popular in China, Kazakhstan, Russia and Ukraine and past decades it is spreading in Africa, Asia, and Europe [141].

Another important approach for maintaining soil health and fertility is the use of beneficial soil microbiomes. Microbes perform countless functions with key role in biogeochemical cycling and sustainability [142]. The utilization of the beneficial microbiomes is an important practice for agro-environmental sustainability. These microbiomes are treasure troves for innovative and potential developments in diverse sectors of agriculture, chemicals, environmental protection, food, and pharmaceuticals. The use of beneficial microbes is the vital practices for the sustainable energy and food production. The current research around the globe is majorly focused on exploring these beneficial microbes for maximizing their application under the limitation of the natural and anthropogenic activities, climate change, use of agro chemicals as these activities are continuously menacing stable agricultural production [143]. In order to fulfill water demand in the near future, it is necessary to rationalize the various means of collecting and storing water. In India, harvesting of rainwater is supposed to contribute in partially meeting the future water requirements. The climate change is expected to make monsoon less reliable as an assured source of water. Thus, efforts are required for more efficient groundwater recharge and rainwater harvesting through adoption and adaptation of technological options. Harnessing excessive monsoon runoff for additional groundwater storage will not only increase the water availability to meet growing demand, but also help to control the damage caused by flooding [144]. Other innovative approaches which may be adopted for water availability include desalination of seawater by evaporation using solar or wind energy which is cost effective and less expensive the cost of tapping groundwater, generation of rainfall using precipitation enhancement such as cloud seeding, and water in surface reservoirs or underground through artificial recharge. Furthermore, increasing irrigation efficiency using another new technology such as sprinkler design with low energy precision application might also be useful [145].

Many NGOs and government organizations are already working on the mitigation strategies for rising climate change. The Indian Council of Agricultural Research under ministry of agriculture and farmers welfare has launched a flagship network project which aims to study the impact of climate change on agricultural sector. The project also takes into account the development and promotion of climate resilient technologies in agriculture which will address vulnerable areas of the country and the output of the projects will help the districts and regions prone to climatic hazards. Rainfed area development scheme is being implemented for promotion of sustainable integrated farming systems. With the help of technological interventions, GOI is preparing efficiently to boost the crop produce and reduce the crop loss. Action against hunger is another important step to cope up with the hunger in scenario of climate crisis. Sankalp Taru Foundation is focusing on protection and conservation of the environment. Mukti is working for the social and economic development and environmental protection of the Sunderbans of West Bengal. Ashoka Trust for Research in Ecology and the Environment is working on issues including biodiversity and conservation, climate change mitigation and development, land and water resources, ecosystem services, and human well-being. Mobius Foundation is working for the environment in Delhi. The Gram Chetna Kendra aims to offer solutions to water problems keeping in mind the frequent damages droughts have induced in

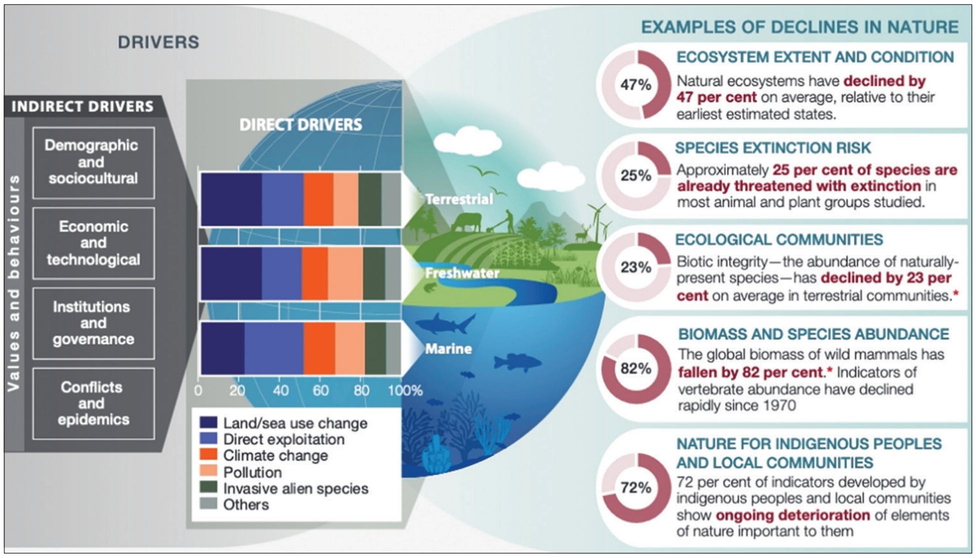

Figure 4: IPBES, global assessment report for policy makers.

Rajasthan. Greenpeace India is working on environment preservation. It has its presence in over 56 countries worldwide across various continents such as Asia, Europe, America, and few others. Greenpeace India promotes four different movements: preserving the oceans, preventing climate change, sustainable agriculture, and preventing another nuclear catastrophe [Figure 4].

8. EFFECTS OF CLIMATE CHANGE ON ECONOMICS

It has long been understood that economic consequences are climate-related. This relationship between climate and economics determines the extent and scale of the market impact of climate change in the next 100 years and beyond. Therefore, recent literature uses panel econometric methods to assess the response of economic results to weather, which is usually defined as implementation based on distribution of climate variables such as precipitation, temperature, and wind [146-148]. This estimation on economically and statistically important effects of weather on an assortment of economic outcomes, including crop yields, industrial output, and labor productivity [149]. The cumulative impact of global climate change is determined by how the world reacts to changes. According to the reports, climate change has already resulted in extreme weather events and a rise in sea level, posing new threats to agricultural production in several parts of the world. Current economic modeling may significantly understate the impact of potentially catastrophic climate change, emphasizing the need for a new generation of models capable of defining a more accurate picture of damages [150-152].

The main dynamic effect is through capital accumulation. Assuming a constant savings rate, if climate change negatively impacts production, the amount of economic investment will be reduced. In the long run, this will lead to lower capital stocks, lower GDP and, in most cases, lower consumption per capita. This effect of capital accumulation can be exacerbated in the context of endogenous growth if low investment slows technological advances while improving labor productivity or human capital accumulation. The second dynamic effect concerns savings. We can expect our forward-thinking agents to predict future climate change and change saving behavior in a perfect world. This, too, will have an impact on capital accumulation, and thus growth and future GDP [153].

Since then, practitioners and academics in development have grappled with the interplay of economic growth and environmental protection. Understanding and acting on these interactions has become critical to development in all countries, particularly in developing ones. The management of the environment has become an essential component of any viable path to poverty reduction and prosperity. Environmental degradation, poor health, and lost economic output result from poor environmental management practices. Poor people are the most vulnerable to these trends, though we must acknowledge that poverty also contributes to them [154,155]. Poor countries and poor people will suffer the most as they rely more on climate sensitive economic activities such as agriculture and possess weaker capability to adapt efficiently. In addition, poor people are also more likely to live in hazard zones and will be more vulnerable to the pests and diseases that follow drought, floods, and heat waves. Climate change can hinder development and growth, increase vulnerability, threaten health and return people to poverty [156]. Given the earth's finite resources, the application of economic principles and empirical findings should be a central component in the quest to meet humanity's aspirations for a good life.

A study investigated that increment in temperature considerably reduces the economic performance in Sub-Saharan Africa. In addition, the relationship between real gross domestic product per capita on one hand, and the climate factors on the other, is intrinsically non-linear has been shown in the study [157]. An integrated assessment model (ENVISAGE), including a CGE-based economic module and a climate module has been used to assess the impact of climate change on economic aspects. Results revealed that the influence of climate change is substantial, particularly for developing countries and in the long run, amelioration and adaptation policies are required to bring about sustainability in economic growth [158]. Another study focused on the impact of the climate change shocks on economic growth. The non-linear autoregressive distributional lag technique has been used for estimation of the asymmetric effect of climate change on the economic growth of Pakistan. The report indicated that at national level, tree planting projects, and safeguard greenery at all costs while at international level, adoption of policies and mitigation strategies to control climate change are of major importance [159]. There is a strong case to be made for greater efforts to increase understanding of the environmental, social, and economic dimensions of sustainable development, which necessitates a greater integration of economics, social sciences, and natural sciences [160].

9. CONCLUSION AND FUTURE PROSPECT

The world is already experiencing the negative effects of climate change from higher temperature to changing precipitation patterns, and severity of natural disasters. Climate change directly or indirectly affects the biodiversity through multitude of pathways. It is extremely challenging to predict the patterns and probabilities of biodiversity loss. Efforts are needed to prevent and manage the negative impacts of changing climate. The uncertainties in global climate changes require integrated multidisciplinary studies to form exact scientific basis for the adapting or lessening the adverse effects of climate change. In fact, the coming decade will be really crucial in determining to what extent humanity can improve the potential devastating effects of climate change. The transition to sustainability will be very difficult, but it is key factor to securing a future for biodiversity. It is important to minimize the ecological and societal consequences of changing biological diversity. The strong initiatives are required for biodiversity conservation, to enhance ecological understanding and ameliorate the consequences.

10. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

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13. ETHICAL APPROVAL

This study does not involve experiments on animals or human subjects.

14. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

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REVIEW ARTICLE

Climate change and its impact on biodiversity and human welfare

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Abstract

Climate change refers to the long-term changes in temperature and weather due to human activities. Increase in average global temperature and extreme and unpredictable weather are the most common manifestations of climate change. In recent years, it has acquired the importance of global emergency and affecting not only the wellbeing of humans but also the sustainability of other lifeforms. Enormous increase in the emission of greenhouse gases (CO_2, methane and nitrous oxide) in recent decades largely due to burning of coal and fossil fuels, and deforestation are the main drivers of climate change. Marked increase in the frequency and intensity of natural disasters, rise in sea level, decrease in crop productivity and loss of biodiversity are the main consequences of climate change. Obvious mitigation measures include significant reduction in the emission of greenhouse gases and increase in the forest cover of the landmass. Conference of Parties (COP 21), held in Paris in 2015 adapted, as a legally binding treaty, to limit global warming to well below 2 °C, preferably to 1.5 °C by 2100, compared to pre-industrial levels. However, under the present emission scenario, the world is heading for a 3–4 °C warming by the end of the century. This was discussed further in COP 26 held in Glasgow in November 2021; many countries pledged to reach net zero carbon emission by 2050 and to end deforestation, essential requirements to keep 1.5 °C target. However, even with implementation of these pledges, the rise is expected to be around 2.4 °C. Additional measures are urgently needed to realize the goal of limiting temperature rise to 1.5 °C and to sustain biodiversity and human welfare.

Keywords Biodiversity · Climate change · Deforestation · Emission of greenhouse gases · Human welfare · Ocean acidification

Introduction

Climate change refers to long-term changes in local, global or regional temperature and weather due to human activities. For 1000s of years, the relationship between lifeforms and the weather have been in a delicate balance conducive for the existence of all lifeforms on this Planet. After the industrial revolution (1850) this balance is gradually changing and the change has become apparent from the middle of the twentieth century. Now it has become a major threat to the wellbeing of humans and the sustainability of biodiversity. An increase in average global temperature, and extreme and unpredictable weather are the most common manifestations of climate change. It has now acquired the importance of global emergency. According to the report of the latest Intergovernmental Panel for Climate Change (AR6 Climate Change 2021), human-induced climate change as is prevalent now is unprecedented at least in the last 2000 years and is intensifying in every region across the globe. In this review the drivers of climate change, its impact on human wellbeing and biodiversity, and mitigation measures being taken at global level are briefly discussed.

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Drivers of climate change

Emission of green-house gases

Steady increase in the emission of greenhouse gases (GHGs) due to human activities has been the primary driver for climate change. The principal greenhouse gases are carbon dioxide (76%), methane (16%), and to a limited extent nitrous oxide (2%). Until recent decades, the temperature of the atmosphere was maintained within a reasonable range as some of the sunlight that hits the earth was reflected back into the space while the rest becomes heat that keeps the earth and the atmosphere warm enough for the sustenance of life forms. Accumulation of greenhouse gases combine with water vapour to form a transparent layer in the atmosphere that traps infrared radiation (net heat energy) emitted from the Earth's surface and reradiates it back to Earth's surface, thus contributing to the increasing temperature (greenhouse effect). Methane is 25 times and nitrous oxide 300 times more potent than CO_2 in trapping heat. Until 2019, the US, UK, European Union, Canada, Australia, Japan and Russia were the major CO_2 producers and were responsible for 61% of world's emissions. Now, China produces the maximum amount of CO_2 (27%) followed by USA (11%) and India (6.6%); on per capita basis, however, India stands ninth.

The emission of GHGs is largely due to the burning of fossil fuels (coal, oil and natural gas) for automobiles and industries which result in carbon emissions during their extraction as well as consumption. The amount of CO_2 in the atmosphere before the industrial revolution used to be around 280 ppm and now it has increased to 412 ppm (as of 2019). Increase in the atmospheric temperature also leads to an increase in the temperature of the ocean. The oceans play an important role in the global carbon cycle and remove about 25% of the carbon dioxide emitted by human activities. Further, some CO_2 dissolves in the ocean water releasing carbonic acid which increases the acidity of the sea water. Rising ocean temperatures and acidification not only reduce their capacity to act as carbon sinks but also affect ocean ecosystems and the populations that relay on them.

Increasing demand for meat and milk has led to a significant increase in the population of livestock and conversion of enormous amount of the land to pasture and farm land to raise livestock. Ruminant animals (largely cows, buffaloes and sheep) produce large amounts of methane when they digest food (through enteric fermentation by microbes), adding to the greenhouse gases in the atmosphere (Sejiyan et al. 2016). To produce 1 kg of meat it requires 7 kg of grain and between 5000 and 20,000 L of water whereas to produce 1 kg of wheat it requires between 500 and 4000 L of water (Pimentel and Pimentel 2003). Anaerobic fermentation of livestock manure also produces methane. According to Patrick Brown, our animal farming industry needs to be changed; using readily available plant ingredients, the nutritional value of any type of meat can be matched with about one twentieth of the cost (See Leeming 2021).

The main natural source of nitrous oxide released to the atmosphere (60%) comes from the activity of microbes on nitrogen-based organic material from uncultivated soil and waste water. The remaining nitrous oxide comes from human activities, particularly agriculture. Application of nitrogenous fertilizers to crop plants is a routine practice to increase the yield; many of the farmers tend to apply more than the required amount. However, it results in nitrous oxide emissions from the soil through nitrification and denitrification processes by microbes. Both synthetic and organic fertilizers increase the amount of nitrogen available in the soil to microbial action leading to the release of nitrous oxide. Organic fertilizers, however, release nitrogen more slowly than synthetic ones so that most of it gets absorbed by the plants as they become available. Synthetic fertilizers release nitrogen rapidly which cannot be used by plants right away, thus making the excess nitrogen available to microbes to convert to nitrous oxide. Presently CO_2 concentration in the atmosphere is higher than at any time in at least 2 million years, and methane and nitrous oxide are higher than at any time in the last 800,000 years (AR6 Climate Change 2021).

Permafrost (permanently frozen soil), widespread in Arctic regions of Siberia, Canada, Greenland, Alaska, and Tibetan plateau contains large quantities of organic carbon in the top soil leftover from dead plants that could not be decomposed or rot away due to the cold. Global warming-induced thawing of permafrost facilitates decomposition of this material by microbes thus releasing additional amount of carbon dioxide and methane to the atmosphere.

Deforestation

Limited deforestation in early part of human civilization was the result of subsistence farming; farmers used to cut down trees to grow crops for consumption of their families and local population. In preindustrial period also, there was a balance between the amount of CO_2 emitted through various processes and the amount absorbed by the plants. Forests are the main sinks of atmospheric CO_2. After the industrial revolution, the trend began to change; increasing proportion of deforestation is being driven by the demands of urbanization, industrial activities and large-scale agriculture. A new satellite map has indicated that field crops have been extended to one million additional km^2 of land over the last two decades and about half of this newly extended land has replaced forests and other ecosystems (Potapov et al. 2021).

In recent decades the demands on forest to grow plantation crops such as oil palm, coffee, tea and rubber, and for cattle ranching and mining have increased enormously thus reducing the forest cover. According to the World Wildlife Fund (WWF), over 43 million hectares of forest was lost between 2004 and 2017 out of 377 million hectares monitored around the world (Pacheco et al. 2021). Amazon Rain Forest is the largest tropical rain forest of the world and covers over 5 million km^2. It is undergoing extensive degradation and has reached its highest point in recent years. According to National Geographic, about 17% of Amazon rain forest has been destroyed over the past 50 years and is increasing in recent years; during the last 1 year it has lost over 10,000 km^2. In most of the countries the forest cover is less than 33%, considered necessary. For example, India's forest and tree cover is only about 24.56% of the geographical area (Indian State Forest Report 2019).

Impacts of climate change

Increase in atmospheric temperature has serious consequences on biodiversity and ecosystems, and human wellbeing. The most important evidences of climate change is the long term data available on the CO_2 levels, global temperature and weather patterns. The impacts of climate change in the coming decades are based on published models on the basis of the analysis of the available data. Comparison of the performance of climate models published between 1970 and 2007 in projecting global mean surface temperature and associated changes with actual observations have shown that the models were consistent in predicting global warming in the years after publication (Hausfather et al. 2019). This correlation between predicted models and actual data indicates that the models are indeed reliable in accurately predicting the global warming and its impacts on weather pattern in the coming decades and their consequences on biodiversity and human welfare.

Weather pattern and natural disasters

One of the obvious changes observed in recent years is the extreme and unpredictable weather, and an increase in the frequency and intensity of natural disasters. Brazil's south central region saw one of the worst droughts in 2021with the result many major reservoirs reached < 20% capacity, seriously affecting farming and energy generation (Getirana et al. 2021). In earlier decades, it was possible to predict with reasonable certainty annual weather pattern including the beginning and ending of monsoon rains; farmers could plan sowing periods of their crops in synchrony with the prevailing weather. Now the weather pattern is changing almost every year and the farmers are suffering huge losses. Similarly the extent of annual rainfall and the locations associated with heavy and scanty rainfall are no more predictable with certainty. Many areas which were associated with scanty rainfall have started getting much heavier rains and the extent of rainfall is getting reduced in areas traditionally associated with heavy rainfall. Similarly the period and the extent of snowfall in temperate regions have also become highly variable.

Increase in the frequency and intensity of natural disasters such as floods and droughts, cyclones, hurricanes and typhoons, and wildfires have become very obvious. Top five countries affected by climate change in 2021 include Japan, Philippines, Germany, Madagascar and India. Apart from causing death of a large number of humans and other animals, economic losses suffered by both urban and rural populations have been enormous. Deadly floods and landslides during 2020 forced about 12 million people leave their homes in India, Nepal and Bangladesh. According to World Meteorological Organization's comprehensive report published in August 2021 (WMO-No.1267), climate change related disasters have increased by a factor of five over the last 50 years; however, the number of deaths and economic losses were reduced to 2 million and US$ 3.64 trillion respectively, due to improved warning and disaster management. More than 91% of these deaths happened in developing countries. Largest human losses were brought about by droughts, storms, floods and extreme temperatures. The report highlights that the number of weather, climate and water-extremes will become more frequent and severe as a result of climate change.

Global warming enhances the drying of organic matter in forests, thus increasing the risks of wildfires. Wildfires have become very common in recent years, particularly is some countries such as Western United States, Southern Europe and Australia, and are becoming more frequent and widespread. They have become frequent in India also and a large number of them have been recorded in several states. According to European Space Agency, fire affected an estimated four million km^2 of Earth's land each year. Wildfires also release large amounts of carbon dioxide, carbon monoxide, and fine particulate matter into the atmosphere causing air pollution and consequent health problems. In 2021, wildfires around the world, emitted 1.76 billion tonnes of carbon (European Union's Copernicus Atmospheric Monitoring Service). In Australia, more than a billion native animals reported to have been killed during 2020 fires, and some species and ecosystems may never recover (OXFAM International 2021).

Sea level rise

Global warming is causing mean sea level to rise in two ways. On one hand, the melting of the glaciers, the polar ice cap and the Atlantic ice shelf are adding water to the ocean and on the other hand the volume of the ocean is expanding as the water warms. Incomplete combustion of fossil fuels, biofuels and biomass releases tiny particles of carbon (< 2.5 µm), referred to as black carbon. While suspended in the air (before they settle down on earth's surface) black carbon particles absorb sun's heat 1000s of times more effectively than CO_2 thus contributing to global warming. When black particles get deposited over snow, glaciers or ice caps, they enhance their melting further adding to the rise in sea level. Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years. Between 2006 and 2016, the rate of sea-level rise was 2.5 times faster than it was for almost the whole of the twentieth century (OXFAM International 2021). Precise data gathered from satellite radar measurements reveal an accelerating rise of 7.5 cm from 1993 to 2017, an average of 31 mm per decade (WCRP Global Sea Level Budget Group 2018).

Snow accounts for almost all current precipitation in the Arctic region. However, it continues to warm four times faster than the rest of the world as the melting ice uncovers darker land or ocean beneath, which absorbs more sunlight causing more heating. The latest projections indicate more rapid warming and sea ice loss in the Arctic region by the end of the century than predicted in previous projections (McCrystall et al. 2021). It also indicates that the transition from snow to rain-dominated Arctic in the summer and autumn is likely to occur decades earlier than estimated. In fact this transition has already begun; rain fell at Greenland's highest summit (3216 m) on 14 August 2021 for several hours for the first time on record and air temperature remained above freezing for about 9 h (National Snow and Ice Sheet Centre Today, August 18, 2021).

In the annual meeting of the American Geophysical Union (13 December 2021) researchers warned that rapid melting and deterioration of one of western Antarctica's biggest glaciers, roughly the size of Florida, Thwaites (often called as Doomsday Glacier), could lead to ice shelf's complete collapse in just a few years. It holds enough water to raise sea level over 65 cm. Thwaites glacier is holding the entire West Antarctic ice sheet and is being undermined from underneath by warm water linked to the climate change. Melting of Thwaites could eventually lead to the loss of the entire West Antarctic Ice Sheet, which locks up 3.3 m of global sea level rise. Such doomsday may be coming sooner than expected (see Voosen 2021). If this happens, its consequences on human tragedy and biodiversity loss are beyond imagination.

The Himalayan mountain range is considered to hold the world's third largest amount of glacier ice after Arctic and Antarctic regions. It is considered as Asian water tower (Immerzeel et al. 2020); the meltwater from the Himalayan glaciers provide the source of fresh water to nearly 2 billion people living along the mountain valleys and lowlands around the Himalayas. These glaciers are melting at unprecedented rates. Recently King et al. (2021) studied 79 glaciers close to Mt. Everest by analysing mass-change measurements from satellite archives and reported that the rate of ice loss from glaciers consistently increased since the early 1960s. This loss is likely to increase in the coming years due to further warming. In another study, a tenfold acceleration in ice loss was observed across the Himalayas than the average rate in recent decades over the past centuries (Lee et al. 2021). Melting of glaciers also results in drying up of perennial rivers in summer leading to the water scarcity for billions of humans and animals, and food and energy production downstream. See level rise and melting of glaciers feeding the rivers could lead to migration of huge population, creating additional problems. Even when the increase in global temperature rise is limited to 1.5 °C (discussed later), it generates a global sea-level rise between 1.7 and 3.2 feet by 2100. If it increases to 2 °C, the result could be more catastrophic leading to the submergence of a large number of islands, and flooding and submergence of vast coastal areas, saltwater intrusion into surface waters and groundwater, and increased soil erosion. A number of islands of Maldives for example, would get submerged as 80% of its land area is located less than one meter above the sea level. The biodiversity in such islands and coastal areas becomes extinct. China, Vietnam, Fiji, Japan, Indonesia, India and Bangladesh are considered to be the most at risk. Sundarbans National Park (UNESCO world heritage Site), the world's largest Mangrove Forest spread over 140,000 hectares across India and Bangladesh, is the habitat for Royal Bengal Tiger and several other animal species. The area has already lost 12% of its shoreline in the last four decades by rising see level; it is likely to be completely submerged. Jakarta in Indonesia is the fastest sinking city in the world; the city has already sunk 2.5 m in the last 10 years and by 2050, most of it would be submerged. In Europe also, about three quarters of all cities will be affected by rising sea levels, especially in the Netherlands, Spain, Belgium, Greece and Italy. The entire city of Venice may get submerged (Anonymous 2018). In USA, New York City and Miami would be particularly vulnerable.

Crop productivity and human health

Many studies have indicated that climate change is driving increasing losses in crop productivity (Zhu et al. 2021). The models on global yield loss for wheat, maize and rice indicate an increase in yield losses by 10 to 25% per degree Celsius warming (Deutsch et al. 2018). Bras et al. (2021) reported that heatwave and drought roughly tripled crop losses over the last 50 years, from − 2.2% (1964–1990) to − 7.3% (1991–2015). Overall, the loss in crop production from climate-driven abiotic stresses may exceed US$ 170 billion year^{-1} and represents a major threat to global food security (Razaaq et al. 2021). Analysis of annual field trials of common wheat in California from 1985 to 2019 (35 years), during which the global atmospheric CO_2 concentration increased by 19%, revealed that the yield declined by 13% (Bloom and Plant 2021). Apart from crop yield, climate change is reported to result in the decline of nutritional value of food grains (Jagermeyr et al. 2021). For example, rising atmospheric CO_2 concentration reduces the amounts of proteins, minerals and vitamins in rice (Zhu et al. 2018). This may be true in other cereal crops also. As rice supplies 25% of all global calories, this would greatly affect the food and nutritional security of predominantly rice growing countries. Climate change would also increase the prevalence of insect pests adding to the yield loss of crops. The prevailing floods and droughts also affect food production significantly. Global warming also affects crop productivity through its impact on pollinators. Insect pollinators contribute to crop production in 75% of the leading food crops (Rader et al. 2013). Climate change contributes significantly to the decline in density and diversity of pollinators (Shivanna 2020; Shivanna et al. 2020). Under high as well as low temperatures, bees spend less time in foraging (Heinrich 1979) adding additional constraints to pollination efficiency of crop species.

The IPCC Third Assessment Report (Climate change 2001: The scientific basis – IPCC) concluded that the poorest countries would be hardest hit with reductions in crop yields in most tropical and sub-tropical regions due to increased temperature, decreased water availability and new or changed insect pest incidence. Rising ocean temperatures and ocean acidification affect marine ecosystems. Loss of fish habitats is modifying the distribution and productivity of both marine and freshwater species thus affecting the sustainability of fisheries and populations dependent on them (Salvatteci 2022).

Air pollution is considered as the major environmental risk of climate change due to its impact on public health causing increasing morbidity and mortality (Manisalidis 2020). Particulate matter, carbon monoxide, nitrogen oxide, and sulphur dioxide are the major air pollutants. They cause respiratory problems such as asthma and bronchiolitis and lung cancer. Recent studies have indicated that exposure to air pollution is linked to methylation of immunoregulatory genes, altered immune cell profiles and increased blood pressure in children (Prunicki et al. 2021). In another study wildfire smoke has been reported to be more harmful to humans than automobiles emissions (Aquilera et al. 2021). Stubble burning (intentional incineration of stubbles by farmers after crop harvest) has been a common practice in some parts of South Asia particularly in India; it releases large amount of toxic gases such as carbon monoxide and methane and causes serious damage to the environment and health (Abdurrahman et al. 2020). It also affects soil fertility by destroying the nutrients and microbes of the soil. Attempts are being made to use alternative methods to prevent this practice.

A number of diseases such as zika fever, dengue and chikungunya are transmitted by *Aedes* mosquitoes and are now largely restricted to the monsoon season. Global warming facilitates their spread in time and space thus exposing new populations and regions for extended period to these diseases. Lyme disease caused by a bacterium is transmitted through the bite of the infected blacklegged ticks. It is one of the most common disease in the US. The cases of Lyme disease have tripled in the past two decades. Recent studies have suggested that variable winter conditions due to climate change could increase tick's activity thus increasing the infections (see Pennisi 2022).

Biodiversity

Biodiversity and associated ecoservices are the basic requirements for human livelihood and for maintenance of ecological balance in Nature. Documentation of biodiversity, and its accelerating loss and urgent need for its conservation have become the main concern for humanity since several decades (Wilson and Peter 1988; Wilson 2016; Heywood 2017; IPBES 2019; Genes and Dirzo 2021; Shivanna and Sanjappa 2021). It is difficult to analyse the loss of biodiversity exclusively due to climate change as other human-induced environmental changes such as habitat loss and degradation, overexploitation of bioresources and introduction of alien species also interact with climate change and affect biodiversity and ecosystems. In recent decades there has been a massive loss of biodiversity leading to initiation of the sixth mass extinction crisis due to human-induced environmental changes. These details are not discussed here; they are dealt in detail in many other reviews (Leech and Crick 2007; Sodhi and Ehrlich 2010; Lenzen et al. 2012; Dirzo and Raven 2003; Raven 2020; Ceballos et al. 2015; Beckman et al. 2020; Shivanna 2020; Negrutiu et al. 2020; Soroye et al. 2020; Wagner 2020, 2021; Anonymous 2021; Zattara and Aizen 2021).

Terrestrial species

There are several effects on biodiversity caused largely by climate change. Maxwell et al. (2019) reviewed 519 studies on ecological responses to extreme climate events (cyclones, droughts, floods, cold waves and heat waves) between 1941 and 2015 covering amphibians, birds, fish, invertebrates, mammals, reptiles and plants. Negative ecological responses have been reported for 57% of all documented groups including 31 cases of local extirpations and 25% of population decline.

Increase in temperature impacts two aspects of growth and development in plants and animals. One of them is a shift in distributional range of species and the other is the shift in phenological events. Plant and animal species have adapted to their native habitat over 1000s of years. As the temperature gets warmer in their native habitat, species tend to move to higher altitudes and towards the poles in search of suitable temperature and other environmental conditions. There are a number of reports on climate change-induced shifts in the distributional range of both plant and animal species (Grabherr et al. 1994; Cleland et al. 2007; Parmesan and Yohe 2003; Beckage et al. 2008; Pimm 2009; Miller-Rushing et al. 2010; Lovejoy and Hannah 2005; Lobell et al. 2011). Many species may not be able to keep pace with the changing weather conditions and thus lag behind leading to their eventual extinction. Long-term observations extending for over 100 years have shown that many species of bumblebees in North-America and Europe are not keeping up with the changing climate and are disappearing from the southern portions of their range (Kerr et al. 2015). Most of the flowering plants depend on animals for seed dispersal (Beckman et al. 2020). Defaunation induced by climate change and other environmental disturbances has reduced long-distance seed dispersal. Prediction of dispersal function for fleshly-fruited species has already reduced the capacity of plants to track climate change by 60%, thus severely affecting their range shifts (Fricke et al. 2022).

Climate change induced shifts in species would threaten their sustenance even in protected areas as they hold a large number of species with small distributional range (Velasquez-Tibata et al. 2013). Pautasso (2012) has highlighted the sensitivity of European birds to the impacts of climate change in their phenology (breeding time), migration patterns, species distribution and abundance. *Metasequoia glyptostroboides* is one of the critically endangered species with extremely small populations distributed in South-Central China. Zhao et al. (2020) analysed detailed meteorological and phenological data from 1960 to 2016 and confirmed that climate warming has altered the phenology and compressed the climatically suitable habitat of this species. Their studies revealed that the temperature during the last 57 years has increased significantly with the expansion of the length of growing season of this species. Climatically suitable area of the species has contracted at the rate of 370.8 km^2 per decade and the lower and upper elevation limits shrunk by 27 m over the last 57 years.

The other impact of climate change on plant and animal species has been in their phenological shift. Phenology is the timing of recurring seasonal events; it is a sort of Nature's calendar for plants and animals. In flowering plants, various reproductive events such as the timing of flowering, fruiting, their intensity, and longevity are important phenological events, and in animals some of the phenological events include building of nests in birds, migration of animal species, timing of egg laying and development of the larva, pupa and adult in insects. Phenological events of both plants and animals are generally fixed in specific time of the year as they are based on environmental cues such as temperature, light, precipitation and snow melt. Phenological timings of species are the results of adaptations over 100 s of years to the prevailing environment. Wherever there is a mutualism between plants and animals, there is a synchrony between the two partners. For example in flowering plants, flowering is associated with the availability of pollinators and fruiting is associated with the availability of seed dispersers and optimal conditions for seed germination and seedling establishment. In animals also, phenological events are adapted to suit normal growth and reproduction. In temperate regions, melting of ice initiates leafing in plants; this is followed by the flowering in the spring. Similarly, warming of the climate before the spring induces hatching of the hibernating insects which feed on newly developed foliage. Insects emerge and ready to pollinate the flowers by the time the plants bloom.

The dates of celebration of the cherry blossom festival, an important cultural event in Japan that coincides with the peak of flowering period of this species and for which > 1000 years of historical records are available, has shown advances in the dates of the festival in recent decades (Primack et al. 2009). The records between 1971 and 2000 showed that the trees flowered an average of 7 days earlier than all the earlier years (Allen et al. 2013). These advances were correlated with increasing temperature over the years. Spring temperatures in the Red River valley, North Dakota, USA have extended the period of the growing season of plants significantly over the years. Flowering times, for which data are available from1910 to1961, have been shown to be sensitive to at least one variable related to temperature or precipitation for 75% of the 178 species investigated (Dunnell and Traverse 2011). The first flowering time has been significantly shifted earlier or later over the last 4 years of their study in 5–15% of the observed species relative to the previous century. *Rhododendron arboretum*, one of the central Himalayan tree species, flowers from early February to mid-March. Generalized additive model using real-time field observations (2009–2011) and herbarium records (1893–2003) indicated 88–97 days of early flowering in this species over the last 100 years (Gaira et al. 2014). This early flowering was correlated with an increase in the temperature.

One of the consequences of a shift in the distributional range of species and phenological timings is the possible uncoupling of synchronization between the time of flowering of plant species and availability of its pollinators (see Gerard et al. 2020). When a plant species migrates, its pollinator may not be able to migrate; similarly when a pollinator migrates, the plant species on which it depends for sustenance may not migrate. Memmott et al. (2007) explored potential disruption of pollination services due to climate change using a network of 1420 pollinators and 429 plant species by simulating consequences of phenological shifts that can be expected with doubling of atmospheric CO_2. They reported phenological shifts which reduced available floral resources to 17–50% of all pollinator species. A long-term study since the mid-1970s in the Mediterranean Basin has indicated that unlike the synchrony present in the earlier decades between the flowering of plant species and their pollinators, insect phenoevents during the last decade showed a steeper advance than those of plants (Gordo and Sanz 2005). Similar asynchrony has been reported between the flowering of *Lathyrus* and one of its pollinators, *Hoplitis fulgida*

(Forrest and Thomson 2011). Asynchrony between flowering and appearance of pollinator has also been reported in a few other cases (Kudo and Ida 2013; Kudo 2014). Such asynchrony could affect the sustenance of plant and/or pollinator species in the new environment.

Marine species

Amongst the marine species, corals are the most affected groups due to the rise in temperature and acidity of oceans. Corals live in a symbiotic relationship with algae which provide colour and photosynthates to the corals. Corals are extremely sensitive to heat and acidity; even an increase of 2–3°F of ocean water above normal results in expulsion of the symbiotic algae from their tissues leading to their bleaching (Hoegh-Guldberg et al. 2017). When this bleached condition continues for several weeks, corals die. Nearly one-third of the Great Barrier Reef, the world's largest coral reef system that sustains huge Australian tourism industry, has died as a result of global warming (Hughes et al. 2018). According to the experts the reef will be unrecognizable in another 50 years if greenhouse gas emissions continue at the current rate.

According to UNESCO, coral reefs in all 29 reef-containing World Heritage sites would cease to exist as functioning ecosystems by the end of this century if greenhouse gas emissions continue to be emitted at the present rate (Elena et al. 2020). Recent assessment of the risk of ecosystem collapse to coral reefs of the Western Indian Ocean, covering about 5% of the global total, range from critically endangered to vulnerable (Obura et al. 2021). Coral reefs provide suitable habitat for thousands of other species, including sharks, turtles and whales. If corals die, the whole ecosystem will get disrupted.

Melting of ice in Arctic region due to global warming is threatening the survival of native animals such as polar bear, Arctic fox and Arctic wolf. Rising of sea level also leads to the extinction of a large number of 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) assessed consequences of sea level rise of 1–6 m for 10 insular biodiversity hotspots and their endemic species at the risk of potential extinction. Their study revealed that 6 to19% of the 4447 islands would be entirely submerged depending on the rise of sea level; three of them, the Caribbean islands, the Philippines and Sundaland, displayed the most significant hotspots representing a potential threat for 300 endemic species. According to the Centre for Biological Diversity (2013) 233 federally protected threatened and endangered species in 23 coastal states are threatened if rising sea is unchecked. Recently more than 100 Aquatic Science Societies representing over 80,000 scientists from seven continents sounded climate alarm (Bonar 2021). They have highlighted the effects of climate change on marine and aquatic ecosystems and have called on the world leaders and public to undertake mitigation measures to protect and sustain aquatic systems and theirs services.

Mitigation measures

The principal mitigation measures against climate change are obvious; they include significant reduction in greenhouse gas emission, prevention of deforestation and increase in the forest cover. To reduce greenhouse gas emission, use of coal and fossil fuels needs to be reduced markedly. As climate change is a global challenge, local solutions confined to one or a few countries do not work; we need global efforts. Many attempts are being made to achieve these objectives at the global level since many decades. Mitigation measures are largely at the level of diplomatic negotiations involving states and international organizations, Governments and some nongovernmental organizations. The Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988. Its mandate was to provide political leaders with periodic scientific assessments concerning climate change, its implications and risks, and also to put forward adaptation and mitigation strategies. In 1992 more than 1700 World scientists, including the majority of living Nobel laureates gave the first Warning to Humanity about climate change and associated problems. They expressed concern about potential damage to the Planet Earth by human-induced environmental changes such as climate change, continued human population growth, forest loss, biodiversity loss and ozone depletion. Conference of Parties (COP) of the UN Convention on Climate Change was established in 1992 under the United Nations Framework Convention on Climate Change (UNFCCC) to discuss global response to climate change. Its first meeting (COP 1) was held in Berlin in March 1995 and is being held every year since then. The Fifth Assessment Report of the IPCC, released in November 2014, projected an increase in the mean global temperature of 3.7 to 4.8 °C by 2100, relative to preindustrial levels (1850), in the absence of new policies to mitigate climate change; it highlighted that such an increase would have serious consequences. This prediction compelled the participating countries at the COP 21 held in Paris in December 2015 to negotiate effective ways and means of reducing carbon emissions. In this meeting the goal to limit global warming to well below 2 °C, preferably to 1.5 °C, compared to preindustrial levels was adapted by 196 participating countries as a legally binding treaty on climate change. It also mandated review of progress every 5 years and the development of a fund containing $100 billion by 2020, which would be replenished annually, to help developing countries to adopt non-greenhouse-gas-producing technologies.

In 2017, after 25 years after the first warning, 15,354 world scientists from 184 countries gave 'second warning to humanity' (Ripple et al. 2017). They emphasized that with the exception of stabilizing the stratospheric ozone layer, humanity has failed to make sufficient progress in solving these environmental challenges, and alarmingly, most of them are getting far worse. Analysis of Warren et al. (2018) on a global scale on the effects of climate change on the distribution of insects, vertebrates and plants indicated that even with 2 °C temperature increase, approximately 18% of insects, 16% of plants and 8% of vertebrates species are projected to loose > 50% geographic range; this falls to 6% for insects, 8% for plants and 4% for vertebrates when temperature increase is reduced to 1.5 °C.

UN Report on climate change (prepared by > 90 authors from 40 countries after examining 6000 scientific publications) released in October 2018 in South Korea also gave serious warning to the world. Some of the salient features of this report were:

- Overshooting 1.5 °C will be disastrous. It will have devastating effects on ecosystems, communities and economies. By 2040 there could be global food shortages, the inundation of coastal cities and a refugee crisis unlike the world has ever seen.
- Even 1.5 °C warming would rise sea levels by 26–77 cm by 2100; 2 °C would add another 10 cm which would affect another 10 million people living in coastal regions.
- Coral reefs are projected to decline 70–90% even at 1.5 °C. At 2 °C, 99% of the reefs would be ravaged.
- Storms, floods, droughts and forest fires would increase in intensity and frequency.
- The world has already warmed by about 1 °C since preindustrial times. We are currently heading for about 3–4 °C of warming by 2100.
- Unless rapid and deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades, achieving the goals of the 2015 Paris Agreement will be beyond reach.
- To keep 1.5 °C target, coal's share of global electricity generation must be cut from the present 37% to no more than 2% by 2050. Renewable power must be greatly expanded. Net CO_2 emissions must come down by 45% (from 2010 levels) by 2030 and reach net zero (emissions of greenhouse gases no more than the amount removed from the atmosphere) around 2050.

This report awakened the world Governments about the seriousness of the climate change. The COP 26 meeting which was to be held in 2020 had to be postponed due to Covid-19 pandemic. The first part of the sixth report of IPCC was released in August 2021 (AR6 Climate Change 2021), just before the postponed COP 26 meeting was to be held; it highlighted that the threshold warming of 1.5 °C (the target of keeping the warming by the end of the century) would reach in the next 20 years itself and if the present trends continue, it would reach 2.7 °C by the end of the century.

Under this predicted climate emergency (see Ripple et al. 2020), COP 26 meeting was held in Glasgow, Scotland between October 31 and November 12, 2021. Nearly 200 countries participated in this meeting. The main aim of the COP 26 was finalization of the rules and procedures for implementation of the Paris agreement to keep the temperature increase to 1.5 °C. A number of countries including USA and European Union pledged to reach net zero carbon emission by 2050. China pledged to reach net zero emissions by 2060 and India by 2070. India also committed to reduce the use of fossil fuels by 40% by 2030. More than 100 countries committed to reduce worldwide methane emissions by 30% (of 2020 levels) by 2030 and to end deforestation by 2030. The average atmospheric concentration of methane reached a record 1900 ppb in September 2021; it was 1638 ppb in 1983 (US National Oceanic and Atmospheric Administration), highlighting the importance of acting on pledges made at the COP 26.

One of the limitations of COP meetings has been nonadherence of the commitment made by developed countries at Paris meeting to transfer US $100 billion annually to developing and poor countries to support climate mitigation and loss of damage, through 2025; only Germany, Norway and Sweden are paying their share. Several experts feel that the adoption of the Glasgow Climate Pact was weaker than expected. According to the assessment of Climate Action Tracker, a non-profit independent global analysis platform, emission reduction commitments by countries still lead to 2.4 °C warming by 2100. However, a positive outcome of the meeting was that it has kept alive the hopes of achieving the 1.5 °C goal by opening the options for further discussion in the coming COP meetings. Apart from implementation of mitigation pledges made by countries, it is also important to pay attention to climate adaptation since the negative effects of climate change will continue for decades or longer (AR6 Climate Change 2021). Investment in early warning is an important means of climate adaptation, which is lacking in many parts of Africa and Latin America.

Conclusions

Climate change has now become the fastest growing global threat to human welfare. The world has realized the responsibility of the present generation as it is considered to be the last generation capable of taking effective measures to reverse its impact. If it fails, human civilization is likely to be doomed beyond recovery. As emphasized by many organizations, the climate crisis is inherently unfair; poorer countries will suffer its consequences more than others. India is one amongst the nine countries identified to be seriously affected by climate change. According to a WHO analysis (2016) India could face more than 25% of all global climate-related deaths by 2050 due to decreasing food availability. China is expected to face the highest number of per capita food insecurity deaths. Bhutan, a small Himalayan kingdom with 60% forest cover, is the most net negative carbon emission country; its GHG emission is less than the amount removed from the atmosphere. Other countries should aim to emulate Bhutan as early as possible.

A number of other options have been suggested to trap atmospheric carbon dioxide (Climate change mitigation—Wikipedia). Carbon storage through sequestration of organic carbon by deep-rooted grasses has been one such approach (Fisher et al. 1994). Several studies from Africa have indicated that introduction of *Brachiaria* grasses in semi-arid tropics can help to increase not only carbon stock in the soil but also yield greater economic returns (Gichangi et al. 2017). Recently a new seed bank, 'Future Seeds' was dedicated at Palmira, Columbia to store world's largest collection of beans, cassava, and tropical forage grasses for the use of breeders to create better performing and climate-resistant crops (Stokstad 2022). *Brachiaria humidicola* is one of the tropical forage grass stored in this seed bank for its potential benefit in carbon sequestration. Lavania and Lavania (2009) have suggested vetiver (*Vetiveria zizanioides*), a C_4 perennial grass, with massive fibrous root system that can grow up to 3 m into the soil in 1 year, as a potential species for this purpose. Vetiver is estimated to produce 20–30 tonnes of root dry matter per hectare annually and holds the potential of adding 1 kg atmospheric CO_2 annually to the soil carbon pool per m^2 surface area. Carbon dioxide capture and storage is another such potential approach. At present it is too expensive and this approach may have to wait until improvement of the technology, reduction in the cost and feasibility of transfer of the technology to developing countries (IPCC Special Report on carbon dioxide capture and storage 2005).

There has been some discussion on the role of climate change on speciation (Levin 2019; Gao et al. 2020). Some evolutionary biologists have observed that the rate of speciation has accelerated in the recent past due to climate change and would continue to increase in the coming decades (Thomas 2015; Levin 2019; Gao et al. 2020). They propose that auto- and allo-polyploidy are going to be the primary modes of speciation in the next 500 years (Levin 2019, see also Gao 2019, Villa et al. 2022). However, extinction of species imposed by climate change may excel positive impact on plant speciation via polyploidy (Gao et al. 2020). The question is will climate change induce higher level of polyploidy and other genetic changes in crop species also that would promote evolution of new genotypes to sustain productivity and quality of food grains? If so, it would ameliorate, to some extent, food and nutritional insecurity of humans especially in the developing world.

Effective implementation of the pledges made by different countries in COP 26 and actions to be taken in the coming COP meetings are going to be crucial and determine humanity's success or failure in tackling climate change emergency. COP 26 climate pact to cut greenhouse gas emissions, end of deforestation and shift to sustainable transport is certainly more ambitious then earlier COPs. There are also many other positive signals for reducing fossil fuels. Scientists have started using more precise monitoring equipment to collect more reliable environmental data, and more options are being developed by researchers on renewable and alternate energy sources, and to capture carbon from industries or from the air (Chandler D, MIT News 24 Oct 2019, Swain F, BBC Future Planet, 12 March 2021). Scotland has become coal-free and Costa Rica has achieved 99% renewable energy. India has reduced the use of fossil fuel by 40% of it installed capacity, 8 years ahead of its commitment at the COP 26.

Further, people are becoming more conscious to reduce carbon emission by following climate-friendly technologies. Human sufferings associated with an increase in natural disasters throughout the world have focussed public attention on climate change as never before. They also realise the benefits of improved air quality by reducing consumption of coal and fossil fuels on health and ecosystems. The demand for electric vehicles is steadily growing. Reforestation is being carried out in a large scale in many countries. Recent studies across a range of tree plantations and native forests in 53 countries have revealed that carbon storage, soil erosion control, water conservation and biodiversity benefits are delivered better from native forests compared to monoculture tree plantations, although the latter yielded more wood (Hua et al. 2022). This has to be kept in mind in reforestation programmes. Hopefully the world will be able to realize the goal of limiting the temperature rise to 1.5 °C by the end of the century and humanity would learn to live in harmony with Nature.

Declarations

Conflict of interest The author declares no conflict of interest.

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Impact of Climate Change on Biodiversity: An Overview

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Review Article

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Impact of Climate Change on Biodiversity: An Overview

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Abstract: Biodiversity is the 'Full variety of Life on Earth'. It includes diversity within species, between species and of ecosystem. Biodiversity plays an important role in climate regulation. Biodiversity conservation will lead to strengthening of ecosystem resilience and will improve the ability of ecosystem to provide important services during increasing climate pressures. But due to anthropogenic activities the global climate has changed since last few decades.This climate change adversely affected the biological resources of the country. This review basically discuss the importance of biodiversity, the consequences faced by the plants, animals, humans and ecosystem owing to the climate change and also control measures or strategies should be taken for the conservation of biodiversity which can protect the earth from the consequenceof climate change.

Keywords: Biodiversity, Climate change, Conservation, Ecosystem, Human health, livelihood, Species.

INTRODUCTION

Biodiversity is the 'Full variety of Life on Earth'. It includes diversity within species, between species and of ecosystem. The term biodiversity is generally used for natural environment and its conservation. According to UNCED (United Nations Conference on the Environmental and Development), 'Biodiversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.' In the simplest sense, biodiversity may be defined as the sum total of species richness, *i.e*. the number of species of plants, animals and microorganisms occurring in a given region, country, continent of the entire globe. Broadly speaking, the term biodiversity includes genetic diversity (Diversity of genes within a species), species diversity (Diversity among species), ecosystem diversity (Diversity at the level of community/ecosystem) and habitat diversity. The genetic diversity acts as a buffer for biodiversity (Verma, 2017a).

Biodiversity is the very basis of human survival and economic development. It helps in maintaining the ecological balance. There is a necessity of ecological balance for widespread biodiversity (Verma 2017b). It plays an important role in the function of an ecosystem by providing many services like nutrients and water cycling, soil formation and retention, resistance against invasive species, pollination of plants, regulation of climate, as well as pest and pollution. Biodiversity is also the source of non-material benefits like spiritual and aesthetic values, knowledge system, cultural diversity and spiritual inspiration. Each and every one should understand the levels and values of biodiversity (Verma 2016), for the larger interest of the world. It is source of inspiration to musicians, painters, writers and other artists (Sharma and Mishra, 2011).

India is one of the 12 mega biodiversity countries in the world and divided into 10 biogeographic regions. Our country accounts for two hotspots out of the 35 global biodiversity hotspots: the Indo-Malayam which includes the Eastern

Himalayas, North-east India and Andaman Islands, and the Western Ghats. Biogeographically, India is situated at the tri-junction of three realms: Afro-tropical, Indo-Malayan and Paleo-Arctic realms, and therefore, has characteristic elements from each of them. This assemblage of three distinct realms makes the country rich and unique in biological diversity. It has a great wealth of biological diversity in its forests, wetlands and in its marine areas. It is estimated that over 46,000 species of plants and 81,000 species of animals are found in India. The flowering plants comprise 15,000 species of which about 7000 species are endemic. Among the animal species diversity more than 50,000 species of insects, 4,000 molluscs, 6,500 other vertebrates, 2,546 fishes, 197 amphibians, 408 reptiles, 1224 birds and 350 species of mammals are found in different habitats (Myers *et al*., 2000).

India is equally rich in traditional and indigenous knowledge, both coded and informal on the use and importance of the biodiversity in the country. For generations, thousands of human communities have lived in the midst of this rich biodiversity and evolved sustainable lifestyles, of a symbiotic nature with the natural bounty around them. In the last two centuries, these equations have been radically challenged and threatened by various factors. Among them are a social and political mandate that favours maximum extraction of natural resources to achieve a certain paradigm of 'development' and a top-down model of conservation that ignores and threatens the very existence of the first allies of conservation–local people whose lives are deeply entwined with that of their surrounding for their physical, social, emotional and moral sustenance, in fact their very livelihood (Roy and Roy, 2015).

With the current trend of globalization and Intellectual Property Rights (IPR) regimes there is an urgent need for proper and scientific quantification and documentation of our biodiversity and associated traditional and indigenous knowledge especially in the developing country. This traditional knowledge is critical to science and society for maintaining the nation's natural resources, for growing its agricultural economy, for sustaining and improving the human health and its life style.

Large scale development and construction have posed significant threat to biodiversity. It has lead to destruction of various fragile ecosystems. Human activities significantly contribute towards destruction of natural habitats. The construction of road, dams, mining activities and other development projects have led to destruction of biodiversity of that region. All these factors related to large scale development are one of the major contributors of threat to biodiversity.

In the recent times India's biodiversity is severely threatened. The important causes of threats to biodiversity are the habitat destruction, invasive species, pollution, population and overexploitation of natural resources. Other prominent factor for the depletion of biodiversity is the rampant poaching. Though stringent laws have been enacted by the government regarding poaching and Wildlife Protection Act (1972) has been passed, which ensures the protection of wildlife and effectively deal with poaching related issues and also many arrests have been made regarding that in recent few years, it is still prevalent and is a cause of concern for the biodiversity and despite the government spending cores on the conservation of animals, the effective implementation of poaching related laws is yet a cause of concern. Similarly overharvesting of forest also depletes the biodiversity of the region.

Another important factor is the conversion of land under forest and grasslands into residential lands and using them for other developmental activities which lead to depletion of biodiversity. Deforestation has a huge impact on the biodiversity and clearing of forests for developmental activities lead to reduced forest cover and also contributes to climate changes affecting ecosystems around the globe.

The biodiversity loss has ecological impact (Kumar Ajay *et al*., 2017) and its main cause is the changes in the environment. Environmental conditions play a key role in defining the function and distribution of organisms, in combination with other factors. Environmental changes have had enormous impacts on biodiversity patterns in the past and will remain one of the major drivers of biodiversity patterns in the future. Environmental changes are studied under the change in climate or changes due to overpopulation, overexploitation of natural resources and deforestation.

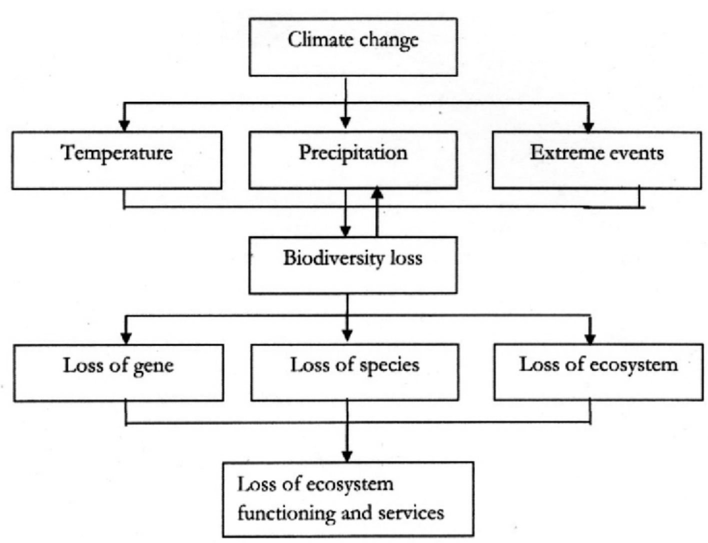

Figure: Link between climate change and its impacts on loss of biodiversity and ecosystem.

Climate Change and its Impact

The word climate refers to the weather variation of any specific area over a period of time. Climate includes the average temperature, amount of precipitation, days of sunlight, and other variables that might be measured at any given site. However, there are also changes within the Earth's environment that can affect the climate. Climate change refers to any change in the environment due to human activities or as a result of natural processes. Climate change refers to significant and long-term changes to a region's climate. These changes can occur over a few decades, or millions of years. Climate change alters entire ecosystems along with all of the plants and animals that live there.

Plants and animals are sensitive to fluctuations in temperature and climate. Evidence of organic evolution clearly indicated that rapid climate changes have been associated with mass extension of plants and animals. Rapid climatic changes could lead to increased diseases, land slide, forest fire which result in destruction of animals and plants. All organisms are adapted to a particular range of climatic conditions. Change in the climatic condition has a danger of extinction of several plants and animals species. Although all species are not directly influenced by changes in environmental conditions but also indirectly influence through their interactions with other species. Indirect impacts are equally important in determining the response of plants to climate change. A species whose distribution changes as a direct result of climate change may 'invade' the range of another species for example, introducing a new competitive relationship.Thus climate change is likely to affect minimum and maximum temperatures and trigger more extreme rainfall events and storms. For the Indian sub-continent, less rainfall in winter and increased precipitation in the summer monsoon are predicted; and in 2050, decreases in winter precipitation by 10-20% and summer by 30% have been projected (Kumar and Chopra, 2009). Climate change results due to both; natural and anthropogenic driver.

Natural drivers involves earth's climate variability caused by changes in the solar radiations, Milankovitch cycle, volcanic eruption, plate tectonics, ocean circulations, earthquakes and so on (Kunzing, 2008). Anthropogenic drivers involves the contribution of human activities to increasing the emission of green house gases like carbon dioxide, methane and nitrous oxide into the atmosphere at an alarming rate in different sectors such as in energy supply (25.9%), industrial sector (19.4%), deforestation (17.4%), agricultural (13.5%), transportation (13.1%), urbanization (7.9%) and waste (2.8%) (Rathore and Jasrai, 2013).

IMPACT OF CLIMATE CHANGE ON ENVIRONMENT

Global warming: The impact of the greenhouse gases is the warming near surface global temperature through the green house effect. The average global temperature has increased by 0.6°C since mid 1800s and is predicted to rise by 1.4-5.8°C by the year 2100. The global warming affects plants, animals and microorganisms both by changing their habitats and by directly affecting their physiological processes. The means sea level has risen by 10 to 20 cm and may further rise to 88cm (Rathore and Jasrai, 2013). Climate change has resulted in an increase in the temperature to about 5°C to the normal and has resulted in the melting of the ice, increase in sea level which is threatening the endemic species (polar bears, walruses, seals, emperor penguins, krill and ringed seal).

Coral bleaching: Another important phenomenon associated with temperature rise is coral bleaching. When corals become affected by the rising temperature and other climatic issues they lose their beautiful colours turning white. The rising temperature results into increase in sea temperatures which negatively impacts the corals resulting in vanishing of the reefs which are considered to be one of the most bio-diverse ecosystems.

Water resources: Climate change affects the water resources thought increased evaporation rate. Increased evaporation rates are expected to reduce water supplies in many regions. The greatest deficits are expected to occur in the summer leading to be decreased soil moisture levels and more frequent and severe agriculture drought. More frequency and severe droughts arising from climate change will have serious and management implication for water resource users. Such droughts also impose costs in terms of wildfires both in control costs and lost timber and related resources.

IMPACT OF CLIMATE CHANGE ON BIODIVERSITY

Only a small change in pattern of climate has severe impact on the biodiversity, altering the habitats of the species and presenting a threat for their survival, making them vulnerable to extinction. Millennium Ecosystem Assessment (MEA) predicts climate change to be the principal threat to the biological diversity (Anonymous, 2007).

Due to increase in temperature several plant species like *Berberisa siatica, Taraxacum officinale, Jasminum officinale* etc.have shifted towards higher altitude in Nainital. Teak dominated forests are predicted to replace the Sal trees in central India and also the conifers may be replaced by the deciduous types. According to Gates (1990) 3°Cincrease in temperature may leads to the forest movement of 2.50 km/ year which is ten times the rate of natural forest movement.

Anonymous (2009) reported that changes in climate affects the normal life cycle of plant. He also reported that invasive species (*Lantana, Parthenium* and *Ageratum conyzoides*) are a threat to native species being more tolerant to climatic variations. Variation in temperature and precipitation patterns can result in more frequent droughts and droughts and floods making indigenous plants more vulnerable to pests and diseases (Tibbetts, 2007).

Slight change in climatic condition leads to the extinction of animal species. For example climate change has resulted in extinction of animals like golden toad and Monteverde harlequin frog (McCarthy *et al*., 2001). Polar bears are in danger due to reduction in Arctic ice cover; North Atlantic whale may become extinct, as planktons which are its main food have shown declination due to climate change. Though the exact impact of climate change on India's natural resources is yet to be studied in detail, pioneering studies show that endemic mammals like the Nilgiri tahr face an increased risk of extinction (Sukumar *et al*., 1995). Further, there are indicative reports of certain species e.g., Black-and rufous flycatcher (Mikania micrantha) shifting their lower limits of distribution to higher reaches, and sporadic dying of patches of Shola forests with the rise in ambient surface temperatures.

The sex ratio of sea turtle disturb because as a result of high temperature more female turtles are produced. Some threatened species (frogs, toads, amphibians, tigers and elephants) are vulnerable to the impacts of climate change like sea level changes and longer drier spells. Changes in ocean temperature and acidification may lead to loss of 95% of the living corals of Australia's Great Barrier Reef (Anonymous, 2007).

Climate change also alters the disease behavior in animals. The devastating amphibian disease chytrid fungus, likely exacerbated by warmer temperatures, has left many amphibian populations dwindling or extinct.

IMPACT OF CLIMATE CHANGE ON ECOSYSTEM

Millennium Ecosystem Assessment (MEA) predicts that only a small change in climate has severe impact on the ecosystems (Anonymous, 2007).

Marine and Coastal ecosystem: 70% of earth's surface is covered by oceans comprising unique ecosystems like mangroves, coral reefs, sea grass beds. Climate change is leading to sea level rise, increased coastal erosion, flooding, higher storm surges, sea salinity ingress, increased sea-surface temperatures, ocean acidification and coral bleaching. Rising sea level presents extreme threat to marine ecosystems which can lead to disturbance in habitat and patterns of survival of marine species. Wetlands and coastal ecosystems are at a huge risk due to increasing sea levels. Many communities have already become climate refugees to evade rising sea level (Anonymous, 2007). Indian coastal areas vulnerable to climate change are Sunderbans, Maharashtra, Goa and Gujarat (Rann of Kutch). Species composition and distribution will surely be affected by such changes (Rathore and Jasrai, 2013). The Sundarbans is the largest natural low-lying mangrove ecosystem in the world, distributed over 10,000 square kilometers. The sea level rise recorded over the past 40 years is responsible for the loss of 28% of the mangrove ecosystem. Modelling suggests that up to 96% of suitable tiger habitat in the Sundarbans could be lost in the next 50–90 years (Loucks *et al*., 2010).

Himalayan ecosystem: Temperatures in the Himalayan ecosystem are increasing at a rate of 0.9°C annually, which is considerably higher than the global average of 0.7°C per decade. Due to this changes mosquito are seeing first time in Lhasa and Tibet cities, located 3490 meters above sea level. There are similar reports of flies at Mount Everest base camp in Nepal. The presence of these insects suggests the possible spread of vectorborne diseases, such as malaria and dengue fever, to areas where cooler temperatures previously protected people from these threats (FAO, 2012).

Island ecosystem: Islands are rich in biodiversity and has high economic importance. But at present due to climate change more than 23% island species are becoming endangered and hence economic loss in the tourism sector.

Inland water ecosystem: It includes lotic and lentic fresh water ecosystem and comprising 0.8% of the earth's surface, but support 6% of the total species. They are rich source of food, income, employment and biodiversity. Changing climatic conditions like rainfall and temperature lead to changes in the phenology, physiology and migration trends of some organisms like migratory fishes and birds.

Forest ecosystem: One third of earth's surface is covered by forest and it is the home place of two third of all terrestrial species. They are also rich biodiversity hotspots. But half of the original forest has been cleared up till now. Green house effect has led to increase in growth of some forest, migration of tree species towards high altitude, increased attack of pest, invasive species and wild fires, hence modifying the composition of forest. According to FAO (2000), due to these changes many animals, primates and 9% of all known plant species are at verge of extinction.

Agriculture: Climate change leads to variability in rainfall patterns, heat stress, spread of pests and diseases and shortening of the crop cycle and affecting plant growth and production. It affects both sustainable and unsustainable agriculture. The unsustainable agriculture has multiple effects (Verma 2017c) and disturbs the ecological balance (Verma 2018a) and biodiversity structure. Biodiversity loss has impacted the fishing and hunting practices by indigenous people posing an implication on their only source of food. By the middle of the century, crop yields could decreases by 30% in Central and South Asia, while by 20% in East and Southeast Asia.

Dry lands and grassland: They have localized species (Wild ass, Kutch etc.) and have varied crops and livestock. The risk of wild fire is increasing which could change the species biodiversity.

IMPACT OF CLIMATE CHANGE ON HUMANS

Climate change leads toan increase in temperature, melting of the ice, increased natural events like floods, droughts, and cyclones displace the humans from their home.Hot climate makes insect pests in general and vectors and pathogens in particular to spread over a wider range and enhances their survival rate. An increase of 1°C in surface temperature is estimated to correspond 10% increase in incidence of insects as pests and insurgence of many diseases like cholera, typhoid etc.; spread of tropical and vector borne diseases like malaria, dengue etc. androdent borne diseases like plague. These diseases have shown a persistent increase in the past 50 years.

Thus global climate changes have major implications on human health. It is obvious that effect on ecosystem will change the distribution and burden of vector borne infectious diseases including bacterial diseases. Changes in epidemiology may already be underway, complex biological changes are associated with change in ecosystem. Water and food borne pathogens create havoc in developing countries that too when conditions are conducive for spread of pathogens and compromise with the hygiene conditions. Green house gases play their role by increasing the carbon emission, due to which the disease curve is increasing faster. Carbon emission is increasing to a dangerous level, making animal lives vulnerable to pathogens and diseases. The increasing sea level rise has already submerged many islands and will soon leave millions of refugees for the world to provide shelter. The sea salinity ingress in the fresh water sources has made land barren and will soon be a threat to the food security.

IMPACT OF HABITAT LOSS, OVERPOPULATION AND OVEREXPLOITATION

Besides climatic change, other human activities are also largely responsible for biodiversity loss. It is estimated that about 27000 species become extinct every year. If this will continues, 30% of world's species may be extinct by the year 2050. The current extinction rate is 100 to 1000 times to that of natural rate of extinction. Other human activities are: habitat destruction, invasive species, pollution, population and overexploitation of natural resources (Kannan and James, 2009).

Climate change will provide new ways for invasive species to encroach on new territory. Natural disasters like storm surges and high winds, which increase in number and severity as the earth warms, spread non-native plants and insects to new territories. Virtually all ecosystems worldwide have suffered invasion by the main taxonomic groups including India. The major invasive alien plant species include *Lantana camara, Eupatorium odoratum, Eupatorium adenophorum, Parthenium hysterophorus, Ageratum conyzoides, Mikania micrantha, Prosopis juliflora* and *Cytisus scoparius*.

Rapidly increasing population has forced down the men to cut down the forests to fulfill the requirements of food and shelter. Deforestation has led to the destruction of the habitats of plants and animals. Loss of habitats is the most important cause of extinction of species. Habitat extinction compels the species to move where they find it difficult to adapt and this may ultimately lead to their extinction. Physically larger species and those living at lower latitude or in the forests or oceans are more sensitive to reduction in habitat area (Drakare *et al*., 2006).

Human activities like deforestation, pollution, overpopulation are ultimately responsible for habitat destruction. Introduction of exotic species is also responsible for the loss of biological diversity. The endemic and other local species may not be able to compete with the exotic species and are unable to survive. Overexploitation, in the form of hunting of animals and plants for their commercial value is one of the major reasons for loss in biodiversity. Illegal wildlife trade is the single largest threat to biodiversity loss. Overpopulation of human and over consumption of natural resources is the root cause of all biodiversity loss (Sharma and Mishra, 2011).

CONCLUSION

It is evident that the loss in biodiversity is due the change in climate. All these changes in environment, adversely affecting the biodiversity, are mainly due to the human activities.The increase in the greenhouse gases is leading to global warming at a faster rate and impacts on biodiversity, ecological balance and humans. The ecological balance is an indispensable need for human survival (Verma 2018b). Every change in the ecosystem process or in ecological balance works on the principle of Newton's law of motion (Every action has an equal and opposite reaction) which may be damaging or complimentary. Even a small change in the climate can lead to the extinction of some vulnerable and sensitive species. Climate change results in the impact on the biodiversity like change in their distribution pattern, migration of species, invasion of invasive species, change in the phonological behaviour like breeding period, migration time etc., increase in the forest fires and pest attacks (Rathore and Jasrai, 2013). To maintain the balance of ecosystem, interaction between the plants, animals and biodiversity needs to be understood, hence promoting its conservation and protection by designating the hotspots as biosphere reserves, increasing aforestation, reforestation and agro-forestry practices. Biodiversity-based adaption and mitigation strategies willenhance the resilience of ecosystems and prevent damage to human and natural ecosystems.

Increasing our understanding of the affects of climate change on biodiversity, developing ways of mitigating such effects and reduced anthropogenic activities are critical to limit such damage. Without conserving the biodiversity and minimizing the anthropogenic activities, it is almost impossible to get the inclusive and sustainable development (Verma, 2019). Thus, there is a growing realization among decision-makers that biodiversity is not an optional bonus in human affairs, but the very foundation of our existence. Moreover, biodiversity conservation tailored to changing climatic conditions is not only necessary to help species and habitats to adapt to change, but such action is also likely to mitigate climate change (FAO, 2012). In terms of agriculture, there is a need for climate resilient farming systems. Climate literacy should be spread and a cadre of Community Climate Risk Managers should be formed in villages. The calamity of climate change should be converted into an opportunity for developing and spreading climate resilient farming techniques and systems (Swaminathan and Keshvan, 2012).

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