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GLOBAL ENVIRONMENTAL CHANGE AND ECOSYSTEM FUNCTIONING: ASSESSING BIODIVERSITY, CLIMATE IMPACTS, CONSEQUENCES AND ADAPTATION

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ABSTRACT

The combination of climatic change with long term anthropogenic forces like habitat destruction, over exploitation and pollution is dramatically shifting the structure and functioning of ecosystems throughout the globe. The paper analyses the interaction of the effects of climate change on biodiversity, processes in the ecosystem, and provision of ecosystem services in the terrestrial, marine, and freshwater environments. As it has been shown, there is already a significant percentage of degraded ecosystems all over the world, and biodiversity is diminishing making ecosystems less resilient to environmental shocks and susceptible to the environment. The article draws attention to the impact of climate change on species distributions, phenology, and ecological interactions which tends to create mismatches in food webs and ecosystem imbalances. The scale and urgency of the changes is further shown by system-level responses, such as coral bleaching, Arctic warming, and frequency of extreme climatic events. Also, the feed-back processes between the climate system and the ecosystems like carbon cycling, albedo effects and thawing of the permafrost are aggravating the global warming. The paper also examines the evolutionary and ecological reaction of the species and it is stressing that although certain organisms may evolve or relocate, many have limited capabilities as a result of the rapid environmental alteration and habitat fragmentation. The reactions of society are also paramount, and climate change presents the policy-making, resources, and food security with challenging issues. This possibility of the shift of regimes in the ecosystems explains why adaptive and foresight strategies are necessary. Finally, the paper will support an interdisciplinary approach, which is all-encompassing and combines ecology science with the socio-economic frameworks. Sustainable development requires building ecosystem resilience, protecting biodiversity, and improving the provision of ecosystem services. The study calls for improved monitoring, innovative modeling approaches, and proactive management strategies to address the escalating impacts of climate change on global ecosystems.

Keywords **:** Climate Change; Biodiversity Loss; Ecosystem Services; Ecosystem Resilience; Anthropogenic Impacts; Ecological Interactions; Species Distribution; Phenology; Regime Shifts; Adaptation Strategies; Global Environmental Change; Sustainability

Introduction

The capacity of ecosystems to deliver essential services for human well-being is increasingly under pressure. Anticipated stresses arising from climate change demand extraordinary and immediate responses. It is crucial to continuously monitor ecosystem health, deepen our understanding of the biological mechanisms that underpin ecosystem service delivery, and develop innovative tools and approaches to sustain and restore resilient ecological and social systems (Smith *et al.*, 2025). Our efforts must be grounded in an ecosystem-based perspective, which has been significantly degraded over the past five decades. Many rivers have been extensively altered, oceans have undergone substantial degradation, coral reefs are nearing collapse as functional ecosystems, and more than half of terrestrial land is now devoted to livestock and agricultural production, often without adequate consideration of the ecological services that have been irreversibly lost.

Several ecological tipping points driven by human activities have already been observed, even before the full measurable impacts of climate change have manifested. Climate change, largely caused by anthropogenic greenhouse gas emissions, is fundamentally reshaping ecological systems. Evidence of these transformations is already widespread: species behavior is changing in ways that disrupt established mutualistic relationships; extinctions are increasing in vulnerable regions; and essential migration pathways are being obstructed due to habitat fragmentation. These developments present serious risks to human societies and require urgent scientific attention and intervention.

Nowadays, the effects of human intervention on the biological systems of the planet are profound and growing. A comprehensive assessment has shown that more than sixty percent of ecosystem services defined as the benefits humans derive from ecosystems have been degraded as a result of human activities, with the most rapid decline occurring within the last fifty years. Human alteration has been so far-reaching to that the world maps today no longer represent pure natural systems but ecosystems that have been modified to a large extent by humans (Alessa *et al*., 2008). Settlement practices like agriculture, grazing, fishing, hunting, deforestation, changing the rivers, urban growth, water abstraction, and application of chemical fertilizers have exerted widespread and, in most instances, growing effects. Such activities have interfered with ecological mechanisms and have significantly decreased the ecosystem services.

Although the conversion of natural systems has greatly boosted the production of food, fuel and fibre, hence sustaining high population growth, other essential ecosystem services that promote the wellbeing of the society have been compromised. Importantly, these trade-offs have not been adequately evaluated or addressed. Climate change is progressing rapidly and is already altering established environmental patterns. These alterations will probably escalate the negative effects of human activities on the sustainability of biological resources in the long term. This discussion identifies the growing implications of climate change on biological systems and interactions on the basis of ecosystem services (Ghaedi, 2026). This point of view is mandatory since ecosystem services are the product of complicated interactions between various biological and physical elements that are crucial to human society. The analysis evaluates the effects on a variety of levels, both on a person level and on the entire ecosystem operation, and the cumulative effects of the environmental degradation during the course of history are also taken into account, which demonstrates the urgent issues that should be considered.

In order to get a clearer perspective on the changes that climate change causes to ecosystem services, the reductionist approach is chosen, where individual biological and ecological units in the provision of the services are examined on their role and service provision contribution to human well-being. This method also takes into account how these components have evolved or would evolve in the nearest future. In any particular environment, living organisms coexist with each other and with the physical environment as they compete over the basic needs like water, nutrients and energy needed in their growth and reproduction. These interactions cause vital ecological processes, such as the absorption of minerals of deep soil layers by living organisms and their subsequent transfer to the soil to the surface, transfer of water through the vegetation to the atmosphere, and absorption of carbon dioxide in the atmosphere to create complex organic structures, and their subsequent release back into the atmosphere through respiration and decomposition (Prütz *et al*., 2026). These processes form the basis of biogeochemical processes of ecosystems. Besides, the communication between organisms contributes to the development of various biochemical defense strategies against predation, and morphological and behavioral adaptation that help them reproduce and exchange genes. These processes include pollination which is usually a process that relies on intermediary species or web of interacting organisms. The combination of these ecological processes and interactions eventually leads to the formation of a functional ecosystem that serves key purpose to human society, which include the provision of clean water, food provision, erosion control, and cultural services. It is therefore clear that human actions can either support or disturb such interactions and as such, human beings should be perceived as active and influential elements in the ecosystem processes.

Ecological Impacts of Biodiversity Loss and Population Decline

There is a considerable variation in the roles played by species in ecosystem functioning. The most abundant species tend to be the main regulators of ecological functions, but in the case when the abundance of certain species is not that great, smaller species may have disproportionately significant effects such as the concept of the keystone species, as defined by ecologists (Lyons *et al*., 2005). Rare species can also be useful in the stability of the community as they increase resistance to biological invasion (Lyons, 2001). Besides, the current species that are not that numerous can grow and gain presence over time because of the changes in the environment supporting the concept that biodiversity acts as a safeguard mechanism in the form of an insurance policy (Hobbs *et al*., 2007).

Some functional groups are particularly important in ecosystem structure maintenance. Considering the example of the apex predators, they play a critical role in community regulation. The species are very susceptible to extinction both on local and global levels, mainly because of the anthropogenic factors including habitat destruction and over exploitation. They are also particularly vulnerable to habitat fragmentation since they tend to need extensive areas. The disappearance of these species may result in the collapse of complete trophic levels hence significantly transforming the operation of an ecosystem.

A compelling example is provided by Meyers *et al*. (2007), who documented the ecological consequences of declining populations of large sharks in the coastal northwest Atlantic. Their reduction triggered a population increase in rays, skates, and smaller shark species. Specifically, when the populations of cownos rays grew, the excess exploitation of the scallops ensued and eventually caused a fishery that had been supported along with a century long history. Other instances of this kind of top-down ecological control have been reported in marine, freshwater and terrestrial environments (Pace *et al*., 1999).

Empirical studies indicate that the more ecological processes species have functional differentiation the less vulnerable the ecosystem is to cascading extinctions (Borrvall *et al*., 2000). Furthermore, the diversity in responses of species, meaning the diverse reaction of species to environmental stressors in functional groups, improves the resilience of the ecosystems to changing environmental conditions (Elmqvist *et al*., 2003). A meta-analysis of the studies that were carried out on eight European grasslands showed that the various species provide unequal contributions to different ecosystem functions. This observation shows that the preservation of multifunctional ecosystems might pose a difficult challenge unless high levels of species diversity are conserved (Hector *et al*., 2007).

Losses in the Ecosystem Service Delivery Chain

Taxonomic and Population-Level Declines

The extent of species and population loss is considerable, and current trends suggest that the primary drivers of these declines remain largely unmitigated. According to the 2008 update of the IUCN Red List, approximately 900 species have gone extinct since the year 1500, including a wide range of vertebrates, invertebrates, and plant species. This figure is likely an underestimate, given the limited knowledge of many taxa and the time lag associated with species assessment and classification.

Bird populations provide one of the most well-documented cases of biodiversity decline. Since 1500, at least 150 bird species have become extinct, and currently, one in eight bird species faces the threat of global extinction. In 20 European countries, approximately 45% of bird species have experienced population declines (Bird life International 2008). Similarly, in the grasslands of the United States, 55% of bird species are declining, while 48% are considered to be of conservation concern.

Mammals species are no exception. Out of the over 5,000 mammal species known, about a quarter are becoming endangered, 76 species of them have already gone extinct since 1500. Also approximately 50 percent of the entire population of mammals is in the state of decline. To terrestrial mammals, the major threat is habitat destruction and then over exploitation. Bycatch and pollution are the 2 most common pressures on the population of the mammals in a marine environment (Schipper *et al*., 2008).

Fresh water species are also at even greater rates of decline with extinction rates estimated to be at least five times higher than those that are found in land or avian systems. The multiplicity of stressors causing these losses are overfishing, water dam construction, water diversion, and pollution.

System-Level Losses

In addition to the disappearance of individual species and population, there is a degradation or loss of whole ecological communities and components of a system. This degradation diminishes the quantity of services that ecosystems provide. It is largely important to know the size and magnitude of these systemic losses as it is what already defines the already reduced baseline on which other forces like climate change will further operate.

Land-based (Earth) Ecosystems.

According to the Millennium Ecosystem Assessment, over 75 percent of the Mediterranean and temperate forests ecosystems have to a large extent been altered significantly by the human activities. Also, almost fifty percent of the terrains in five of the thirteen significant biomes have been converted. Boreal forests and tundra areas, which are mostly not conducive to agriculture, are the only relatively untouched parts of the territory, but even there, the signs of the climate change are already extremely noticeable (Chapin *et al*., 2008).

It is projected that conversion of habitat in future will be focused on the tropical and subtropical forests and grasslands. Not only are these regions rich in biodiversity, but also they are important in the maintenance of ecosystem services like water control, food supply and timber resources. The further change of these systems is dangerous to the sustainability of the ecological state and the human welfare.

Marine Ecosystems

There has been extensive degradation of marine environments in the past decades. Habitat destruction, overfishing, invasion, ocean warming, acidification, pollution, and nutrient runoff have made complex ecosystems like coral reefs and kelp forests simple and less productive through the combined effects (Bohn *et al*., 2025).

Simplified microbial life systems are replacing previously simple, biologically diverse coastal waters with complex food webs and large marine organisms. There is frequent unstable ecosystems in these modified ecosystems including harmful algal blooms, jellyfish population bursts, and disease outbreaks.

As the meta-analysis by Jackson illustrates, the percentage of large vertebrates, oyster populations, seagrass habitats, and wetlands lost in coastal and estuarine ecosystems have been more significant by over 80%, 90, 65 and 67 percent, respectively, compared to historical conditions at their baseline settings. The last half-century has seen an expansion of fishing activities to areas deep into the ocean and this has increased ecological pressure (Morato *et al*., 2006).

The impacts of environmental stress on the coastal systems are also on the rise as is illustrated by the quick rise in hypoxic dead zones that occupy around 245,000 km^2 of the marine environments (Diaz *et al*., 2008). There has also been a growth in oligotrophic (nutrient-depleted) ocean areas, by approximately 6.6 million km^2 over the past 20 years, which is also probably related to global warming.

The changes pose a threat to the major services of the marine systems to the ecosystem, including fisheries, tourism, and nursery habitats that are important to marine life. The ecological importance of seabed communities (benthic ecology) is especially significant because they help to produce food, recycle nutrients, and control climate. Biodiversity greatly contributes to the operation and effectiveness of such systems (Danovaro *et al*., 2008).

Like the coastal systems, coral reefs and mangrove ecosystems play a critical role in sustaining the livelihood of the human beings. The coral reefs alone support almost 500 million people through food, protection and economic support(Amos, 2025). Nevertheless, it has been estimated that some 40 percent of the coral reefs have been destroyed within the last forty years and the losses continue at a rate of 1-2 percent every year. This is of grave danger to the large population of the species that rely on these ecosystems.

Freshwater Ecosystems

Some of the most biologically diverse systems on earth are freshwater ecosystems (wetlands and rivers) and they are important ecosystem providers. They are also one of the most altered with the effect of human activities despite their significance. Human interventions have been more concerned with the extraction of provisioning services like water supply, hydro-electric power, transportation and food production often at the cost of other important services like carbon storage, temperature regulation, water purification, flood management, and cultural values.

In the world, over fifty percent of the wetlands worldwide have either been converted or lost (Palmer *et al*., 2009). The ecological condition of about 42% of wadeable streams in the United States is poor, with the stream having low biodiversity, and over half have undergone important changes in flow regimes. In the U.S, agricultural activities cause about 60 percent of the pollution in freshwater systems, as opposed to urban and industrial sources that are the major sources of water pollution in Europe.

Another example of human alteration of rivers is the building of over 45000 large dams (greater than 115 meters high) which influence about 50 percent of the world big rivers. These dams change the patterns of natural flows, sediment transportation, and thermal conditions, affecting the ecological processes and lowering the biodiversity. Alterations in the flow of rivers have also contributed to the homogenization of the fish populations in the global population with the species adapted to the changed conditions substituting the native ones.

Large scale changes like these are components of larger changes that are taking place on the watersheds of the world, created by the human demands of water, energy and arable land. These activities have led to massive loss of species especially in areas that are highly developed (Moore *et al*., 2005).

Climate Change, Ecosystem Services, Biodiversity

It is in the last half-century that a significant amount of ecosystem degradation has taken place. The rising effects of the climate change are currently confronting the already poor ecosystems and limiting them even more in offering the necessary services. The changes and the new evidence reveal the increasing effects of climate warming on biodiversity and ecosystem operation, which has direct implications on the provision of ecosystem services(Climate Change Advisory Council, 2025).

The Future Under Climate Change

In the future, the trend of climate change is likely to have significant effects on the ecosystems across the world. The two main causes such as the rising levels of carbon dioxide (CO_2) and other greenhouse gases (especially nitrogenous compounds created by industrial and agricultural activities) have direct impacts on biological systems (Kumar & Singh, 2026).

Along with these direct effects, climate change brings about indirect effects that mainly come in the form of the increase in global temperatures. Warming affects, the metabolism of organisms and changes the ecological interactions. Moreover, the fluctuations in the sea level, vegetation structure, and hydrological cycles provide some further levels of complexity, which impacts both physical and biological systems (Mouratidis *et al*., 2025).

Climate change, both directly and indirectly, has a very high level of complexity due to the fact that it is taking place at rates and scales that have never before been witnessed. Such alterations endanger the sustainability of the ecosystems and their capacity to support the services that human societies rely on.

Dissimilar Reactions of organisms to climate change

Climate change has a range of effects on organisms, which are mostly determined by ecological attributes and evolutionary backgrounds. The ability to adapt to environmental change is very different between species and even among individuals of species. Climate change presents a more complicated challenge compared to the previous anthropogenic demands, including over exploitation and habitat destruction, because it affects the interacting species of ecological communities unevenly.

The implications of these differential effects are extensive to the ecological relationships, such as, plant-pollinator relationships, plant-herbivore relationships and ecological networks in general. Climate change is equally happening too quickly that it may surpass the adaptive ability of most of the organisms preventing them to adapt or move to more favorable conditions. The degree of responding in the species is determined by the duration of the life cycle, genetic variation, and phylogenetic barriers (Sharma *et al*., 2024).

Systems of different taxonomic groups and ecosystems will thus have different rates of response. Examples include a slow process like soil formation which takes thousands of years to take place through interactions between climate and living organisms. The swift changes in the distribution of species due to climate change can lead to new species assemblage and the lack of fit between a species and its original environmental factors. Also, completely novel climatic conditions can arise with which no biological community recorded in history has ever existed (Williams *et al*., 2007).

Ecosystem Change and Operational effects

Climate change biological responses are very complex and therefore, are likely to cause major changes in the structure and functioning of the ecosystems in a manner that may affect the provision of ecosystem services. The traces of such changes are already numerous. The effects of anthropogenic climate change have been reported throughout all continents, oceans, and among the major taxonomic groups (Camille Parmesan *et al*., 2006) acknowledged.

These changes are also pointed out by empirical research. Jonathan Lenoir and others (2008) studied 171 plant species in the arbor in Western Europe with sea-level to 2600 meters of elevation. Their results showed a mean positive change in species distribution of about 29 meters in a period of ten years. Nevertheless, such shifts did not differ universally: species with shorter life cycles (herbaceous) showed more shifts in distribution compared to species with longer life cycles (woody), and species at higher elevation were more vulnerable to warmer temperatures compared to those at lower elevation. These trends indicate that there is a break in the habitual pattern of community formations due to warming of the climate.

The changing Species Distributions

Further proof of redistribution patterns is presented in long-term ecological studies. The result of a 50-year study carried out in the Yosemite National Park revealed that almost half of the 28 species studied showed a generalization upwards shift by about 500 meters in the ranges of elevation (Moritz *et al*., 2008). The lowland species spread to elevated areas whereas the high-elevation species had to shrink their ranges, which means reorganization of the ecological community. But these changes cannot always occur everywhere. However, as Craig Moritz and his colleagues observe, these adjustments in the range might not happen in those areas where the migration routes are limited due to the conversion of land to human land-use patterns. This points out the synergistic effect of habitat fragmentation and climate change in the formation of biological responses.

The distributional changes are not only restricted to temperate areas; the same is also happening in the tropical ecosystems including the plant and animal species (Colwell *et al*., 2008). Highly dispersing species and general thermal tolerant species have a higher probability of altering their ranges. Conversely, species whose habitat becomes fragmented, restricted migration routes, or other geographic barriers - including river systems that do not have appropriate directional flow, may not be able to move. As an illustration, certain fish species which rely on colder water conditions might not have access to migrate to the right habitats because of such limitations (Matthews *et al*., 1990).

Phenology and Species Interactions Disruption

Climate change is not merely beginning to change the distributions of species but is also affecting the time of biological events (phenology) and the ecological relationship structure. E.E. The results of the study by Cleland and colleagues (2007) indicate that 542 species of plants in Europe showed an increase in leaf emergence at the beginning of the spring by an average of 2.5 days per decade, and in fruit ripening by an average of 2.4 days per decade over a 30-year period (1971-2000). About three-fourths of the species had earlier season development. Early season species were the most affected and other late season species were delayed.

More experimental evidence shows that the higher the CO_2 concentration in the atmosphere, the higher the possibility that plant phenology will have different effects on species groups. As shown by Cleland *et al*. (2006), high levels of CO_2 led to the flowering of herbaceous plants (forbs) and retarded flowering in grasses and this clearly showed that species responded differently to climate drivers.

The animal behavior also exhibits the changes. Josh Van Buskirk *et al*. (2009) observed 78 species of songbirds through a period of 46 years and their study resulted in the conclusion that the spring migration has started much earlier and on the other hand the timing of the autumn migration has been relatively the same. Just as in the case of plants, there were great differences in reactions across species, especially in the fall. Such variations also imply that the changes in climate could introduce changes in the pattern of community assembly than it was historically.

Community-Level Consequences

These phenological changes have increased ecological implications, at least on a community scale, and especially in regards to food web synchronization among species. Marcel Visser and Christiaan Both showed that when people change the timing of the occurrence of life cycle events then there is possibly incompatibility between the species and their food sources. Phenology of a species in this situation may lag or accelerate in relation to the supply of their primary food source, which may lead to lower survival and reproductive success.

In marine ecosystems the mismatches are still more complicated, they include several trophic levels and functional groups. Research suggests that there are high discrepancies in production and consumption at these levels, which cause disruption to the ecosystem operations and stability (Edwards *et al*., 2004).

System-Level Responses to Climate Change

The effects of climate changes have already been seen clearly at the ecosystem level, especially in the delicate ecosystems like the Arctic and coral reef systems. Mass coral bleaching is one of the most notable examples that are caused by the increase of sea surface temperatures. This has resulted in massive killing of corals in tropical areas and subsequent destruction of the reef formation and ecological processes (Hoegh-Guldberg O, 1999).

There have been six major global bleaching events since the first coral bleaching was being recorded in scientific circles in 1979. These events are getting higher and stronger and it is predicted that the bleaching may be an annual event by the year 2030-2050 in case the trend of warming continues. Increased absorption of carbon dioxide in the atmosphere leads to ocean acidification, which further exacerbates the pressure on the coral ecosystems by lowering the supply of carbonate ions needed to support the coral calcification.

As an illustration, the coral reefs at the great barrier reef and in Thailand are presently growing and therefore calcifying at about 15 percent slower than it used to be in the year 1980. Such a decrease is the worst in the 400-year coral record that has been studied in the past. Such changes have profound implications for ecosystem services. In the Coral Triangle which includes six Southeast Asian nations over 100 million people are increasingly vulnerable to declining food security, sea-level rise, and more intense storm events.

Extreme Climate Events and Ecosystem Dynamics

Extreme weather events in many locations do not have an average climatic condition but a strong impact on the structure and functioning of the ecosystem. To illustrate, heavy rainfall and the storm activities that come with the El Nieno occurrences in California have been proved to transform the ecosystem that was formerly found in the mountainous areas to the coastal marine ecosystems. Such disturbances may reset ecological succession and even cause a regime shift, e.g., the conversion of grasslands to shrublands (Hobbs *et al*., 1995).

A study conducted by Jorg Jentsch and Carl Beierkuhnlein (2008) puts emphasis on ecological impacts of extreme climatic occurrence such as cyclones, droughts, heat waves, heavy rainfall, and flooding. The frequency and the intensity of these disturbances are likely to rise, being one of the leading causes of the ecological disturbance. Consequently, there is a growing need for new experimental approaches to better understand ecosystem resilience and to identify systems that can withstand such disturbances (Jentsch *et al*., 2007).

Ecosystem Feedbacks to the Climate System

Ecosystems did not receive much consideration in the early global climatic model. Nevertheless, in recent models, land-ocean-atmosphere interactions are becoming more frequently used to understand that the type and condition of the ecosystem play a major role in local, regional and global climate processes (Sellers *et al*., 1997).

Numerous feedback processes in the ecosystem have the propensity of enhancing the trends of warming. Reduced snow cover and vegetation change are already taking place in the Arctic which is considered to be one of the first signals of climate change. These transformations shift the surface reflectivity (albedo) and thus influence the absorption of solar radiation and strengthen the warming patterns (Betts, 2000). Similar albedo-related feedbacks are now being observed in other parts of the world, where land surface changes modify energy balance dynamics (Bala *et al*., 2007).

One of the most important crises among others is the thawing of permafrost in the Arctic areas. These frozen soils have huge quantities of carbon and methane that might be released in the atmosphere and thereby contribute greatly to global warming. This positive feedback is also enhanced by the rising levels of the wildfire activity in high-latitude areas (Field *et al*., 2005).

The climate change in subtropical drylands would lead to the heightened aridity, which would add to the process of desertification, forest degradation and deforestation. The consequences of these changes have far reaching effects on biodiversity, the concentration of carbon and dusts in the atmosphere, and livelihoods of the vulnerable human populations.

Currently, terrestrial plus marine ecosystems up-take over fifty percent of human-caused CO_2 emissions. Nevertheless, the ability of terrestrial systems to perform the role of carbon sinks is nearing the saturated stage and may change into a net source of carbon sources in this century. Likewise, the oceans which had been viewed as an almost inexhaustible carbon sink are also beginning to exhibit a decreased carbon uptake, especially in the crucial areas like the Southern Ocean (Thomas *et al*., 2004)

Future Projections and Ecosystem Responses

To be able to learn the ways in which the ecosystem services can be preserved in the context of changing climatic conditions, it is essential to adapt both ecologically and socially. The evolution of species to environmental change and how to formulate strategies to maintain the ecosystem services are one of the significant fields of research (Rahmati, 2024).

The ecological niche or climate envelope models are also known as predictive models which are being extensively applied in order to determine future distribution of species in the face of climate change. These models have also given significant information on risks of extinction. As an example, Chris D. Thomas and others (2004) have determined that, in moderate warming conditions projected to occur in 2050, virtually between 15 and 37 of the species would be committed to extinction. This idea does not mean that these species are going to disappear immediately but suggests that the species will not be able to survive in the long-term because of the loss of habitat and environmental alteration.

Additional indications indicated by meta-analyses indicate that in the event that global temperatures increase by 23C above the preindustrial levels, about 2030 percent of plant and animal species would have a considerably high chance of extinction. These results are very generally in agreement with other large-scale studies although methodological and coverage variations exist (Pearson *et al*., 2003).

Although climate modeling is useful in giving projections, it relies on a number of assumptions that do not necessarily reflect the complexity of ecology. Inter-model variability should be approached with caution and to make proper estimates of the risk of extinction, species-specific biological and ecological characteristics should be used (Deutsch *et al*., 2008).

A weakness of these models is that they do not completely explain variations in the adaptability of species, their rates of environmental change and interaction with other stressors in the world. As an example, the invertebrate studies have shown that the temperate species tend to have a wider thermal tolerance range compared to tropical species. Temperature rise will probably be higher in the temperate areas, but the cold-blooded species (tropical ones) will suffer more due to the fact that they are already close to their threshold temperature.

In a similar vein, in-depth studies of the space modelling of the genus Protea (Pelletier *et al*., 2009) show that the persistence of the species is very dependent on the ecological characteristics of various species including ability to survive poor soil conditions and the interaction of the ecological characteristics with the environment such as fire frequency. These results highlight the need to include ecological complexity when making future predictions of the effects of climate change.

Evolutionary Responses of Populations

The main way that populations will react to climate change is by evolving in response to the changes. Although most people tend to believe evolutionary processes are too slow to be able to keep up with the rapid environmental change this is not always the case. In some circumstances, evolution can be rather rapid; but it may not be easy to sustain rapid evolution over long periods, especially when generation times are long.

The fact is that there is empirical evidence on the possibility of rapid evolutionary change. As an example, annual plant, *Brassica rapa*, has shown quantifiable microevolutionary reactions to shifts in climatic variation in long-term drought situations. However, in spite of these examples, the speed with which natural systems can adapt to the accelerating climate change has obvious limits. These boundaries are dictated not only by the pace of evolutionary changes but also by the ability of species to change the composition of their geographic areas depending on temperatures.

More studies on the subject are necessary to enhance predictive capability on the potential reaction of biological systems to the current climate change. Evolutionary constraints and dispersal capacities will be better understood and reliable projections of ecological outcomes will be made.

Societal Responses and Adaptation Challenges

Climate change continues to not only change ecosystems and biodiversity and ecosystem services but poses serious problems to the decision-makers, such as resource managers, policymakers, and stakeholders. A key challenge is dealing with uncertainties present about future climatic conditions and possible unexpected and non-linear responses in the ecosystem.

The local adaptation decisions will become less and less attached to traditional practices. An example is when farmers need to deal with new discrepancies in the phenology (i.e. the timing of the forage crops and the natural predator of herbivorous insects). It can result in additional dependence on chemical inputs such as insecticides. On the same note, the timing of planting the annual crops is also getting more intricate, since it is affected by the soil conditions through uncertain patterns of precipitations in winter and spring.

Climate change is predicted to exacerbate food insecurity especially in vulnerable areas at larger spatial scales. It has been estimated that by 2030, most of the already food insecure regions will experience even more difficulties. The necessary institutional, technological, and social changes to adapt to them will be quite significant. As pointed out by Andrew J. Challinor and others (2009), there is a need to work out integrated modeling systems that integrate both socio-economic and biophysical models to more effectively understand and forecast crop yields and social response in changing climatic conditions.

Ecosystem Resilience and Regime Shifts

Less resilient ecosystems might still be able to operate and offer services in stable conditions but are very sensitive to any disruptive factor that might occur suddenly like floods or extreme rains. Under these circumstances, ecosystems can reach material boundaries and transition to other regimes- a process otherwise known as a regime shift (Folke *et al*., 2005).

Such transitions lead to significant and even irreversible shifts in service delivery and structure of the ecosystem. The classical view of the ecosystems in the full balance is being more and more substituted by the realization of the social-ecological systems being dynamic and complex. The transformations inside these systems might happen abruptly instead of slowly changing, which can be difficult to manage using the conventional economic models and sustainability frameworks that have become accustomed to predictability and change in small steps.

Climate Change as an Opportunity for Transformation

Climate change can also be seen as an opportunity to induce innovation, learning and adaptive capacity in societies despite its problems. Being proactive towards climate-related issues can contribute to the state of resiliency and facilitate the working out of future-oriented solutions to the management of social-ecological systems.

Two areas of interest are the two that future studies should be done on:

1. discovering the existence of a variety of adaptation pathways in the interrelated social-ecological systems, and
2. discussing the way innovative ecosystem management strategies can be used to support beneficial changes and sustainability.

A Call to Action

Climatic changes are putting further stress on natural systems that have been already impaired and which are the keystones to human lives. To deal with this difficulty, the global scientific community needs to be committed again and work together. Beyond existing understanding about the linkage between biodiversity and ecological services, there is a need to advance knowledge on biodiversity in order to decrease uncertainty and provide the necessary response to climate change.

The following priorities should be followed in order to enhance resilience and maintain ecosystem services:

a) Develop broad maps and ecological services valuation frameworks of ecosystem services on a variety of spatial and time scales (Maler, 2000)

b) Enhance basic scientific studies to enhance knowledge on the interactions between biodiversity, ecosystem processes, ecosystem services and human needs including adaptive abilities.

c) Design and develop new experiments and modeling methods that combine various drivers of global change to aid adaptation strategies in a wide range of ecological systems that include agricultural systems.

d) Enhance proactive conservation, restoration, and management of natural resources that maximize the provision of ecosystem services, consider trade-offs and improve resilience to the changing environmental conditions. These approaches should further appreciate the fact that it may not always be possible to rehabilitate ecosystem to their past conditions.

e) Increase scientific attention toward adaptation strategies that address unavoidable changes in ecosystem functioning and service provision, while simultaneously identifying and modifying human activities that contribute to climate change.

References

Alessa, L. and Chapin, F. S. (2008). Anthropogenic biomes: A key contribution to earth-system science. *Trends in Ecology & Evolution*, **23**, 529–531.

Amos, R. (2025). A critical analysis of the global biodiversity framework. *Journal of International Wildlife Law & Policy*, **28**(2), 123–192. https://doi.org/10.1080/13880292.2025.2539577

Bala, G., Caldeira, K., Wickett, M., Phillips, T. J., Lobell, D. B., Delire, C. and Mirin, A. (2007). Combined climate and carbon-cycle effects of large-scale deforestation. *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 6550–6555.

Betts, R. A. (2000). Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. *Nature*, **408**, 187–190.

BirdLife International. (2008). *State of the world's birds: Indicators for our changing world*. BirdLife International.

Bohn, F. J., et al. (2025). Current perspectives on biosphere research 2024–2025: Climate–biodiversity interactions. *Biogeosciences*, **22**, 2425–2450. https://doi.org/10.5194/bg-22-2425-2025

Borrvall, C., Ebenman, B. and Jonsson, T. (2000). Biodiversity lessens the risk of cascading extinction in model food webs. *Ecology Letters*, **3**, 131–136.

Challinor, A. J., Ewert, F., Arnold, S., Simelton, E. and Fraser, E. (2009). Crops and climate change: Progress, trends, and challenges in simulating impacts and informing adaptation. *Journal of Experimental Botany*, **60**, 2775–2789.

Chapin, F. S., Trainor, S. F., Huntington, O., Lovecraft, A. L., Zavaleta, E., Natcher, D. C., McGuire, A. D., Nelson, J. L., Ray, L. and Calef, M. (2008). Increasing wildfire in Alaska's boreal forest: Pathways to potential solutions of a wicked problem. *BioScience*, **58**, 531–540.

Cleland, E. E., Chiariello, N. R., Loarie, S. R., Mooney, H. A. and Field, C. B. (2006). Diverse responses of phenology to global changes in a grassland ecosystem. *Proceedings of the National Academy of Sciences of the United States of America*, **103**, 13740–13744.

Cleland, E. E., Chuine, I., Menzel, A., Mooney, H. A. and Schwartz, M. D. (2007). Shifting plant phenology in response to global change. *Trends in Ecology & Evolution*, **22**, 357–365.

Climate Change Advisory Council. (2025). *Annual review 2025: Biodiversity and ecosystem services*.

Colwell, R. K., Brehm, G., Cardelus, C. L., Gilman, A. C. and Longino, J. T. (2008). Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science*, **322**, 258–261.

Danovaro, R., Gambi, C., Dell'Anno, A., Corinaidesi, C., Fraschetti, S., Vanreusel, A., Vincx, M. and Gooday, A. J. (2008). Exponential decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. *Current Biology*, **18**, 1–8.

Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., Ghalambor, C. K., Haak, D. C. and Martin, P. R. (2008). Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences of the United States of America*, **105**, 6668–6672.

Diaz, R. J. and Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. *Science*, **321**, 926–929.

Edwards, M. and Richardson, A. J. (2004). Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, **430**, 881–884.

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B. and Norberg, J. (2003). Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment*, **1**, 488–494.

Field, C. B., Lobell, D. B., Peters, H. A. and Chiariello, N. R. (2007). Feedbacks of terrestrial ecosystems to climate change. *Annual Review of Environment and Resources*, **32**, 1–29.

Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005). Adaptive governance of social–ecological systems. *Annual Review of Environment and Resources*, **30**, 441–473.

Ghaedi, Z. (2026). Nature-based solutions, climate change, and biodiversity: A systematic review. *Environmental Research Advances*. https://doi.org/10.1016/j.nbsj.2026.100302

Hector, A. and Bagchi, R. (2007). Biodiversity and ecosystem multifunctionality. *Nature*, **448**, 188–190.

Hobbs, R. J. and Mooney, H. A. (1995). Effects of episodic rain events on Mediterranean-climate ecosystems. In J. Roy, J. Aronson and F. di Castri (Eds.), *Time scales of biological responses to water constraints* (pp. 71–85). SPB Academic Publishing.

Hobbs, R. J., Yates, S. and Mooney, H. A. (2007). Long-term data reveal complex dynamics in grassland in relation to climate and disturbance. *Ecological Monographs*, **77**, 545–568.

Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research*, **50**, 839–866.

Jentsch, A. and Beierkuhnlein, C. (2008). Research frontiers in climate change: Effects of extreme meteorological events on ecosystems. *Comptes Rendus Geoscience*, **340**, 621–628.

Jentsch, A., Kreyling, J. and Beierkuhnlein, C. (2007). A new generation of climate-change experiments: Events, not trends. *Frontiers in Ecology and the Environment*, **5**, 365–374.

Kumar, A. and Singh, R. (2026). Climate change impacts on global biodiversity and ecosystem resilience: A comprehensive review. *Environmental Sustainability Journal*. https://doi.org/10.9734/ijecc/2026/v16i15230

Lenoir, J., Gegout, J. C., Marquet, P. A., de Ruffray, P. and Brisse, H. (2008). A significant upward shift in plant species optimum elevation during the 20th century. *Science*, **320**, 1768–1771.

Lyons, K. G., Brigham, C. A., Traut, B. H. and Schwartz, M. W. (2005). Rare species and ecosystem functioning. *Conservation Biology*, **19**, 1019–1024.

Lyons, K. G. and Schwartz, M. W. (2001). Rare species loss alters ecosystem function—invasion resistance. *Ecology Letters*, **4**, 358–365.

Mäler, K. G. (2000). Development, ecological resources and their management: A study of complex dynamic systems. *European Economic Review*, **44**, 645–665.

Matthews, W. J. and Zimmerman, E. G. (1990). Potential effects of global warming on native fishes of the Southern Great Plains and the Southwest. *Fisheries*, **15**, 26–32.

Moore, A. A. and Palmer, M. A. (2005). Invertebrate biodiversity in agricultural and urban headwater streams: Implications for conservation and management. *Ecological Applications*, **15**, 1169–1177.

Morato, T., Watson, R., Pitcher, T. J. and Pauly, D. (2006). Fishing down the deep. *Fish and Fisheries*, **7**, 24–34.

Moritz, C., Patton, J. L., Conroy, C. J., Parra, J. L., White, G. C. and Beissinger, S. R. (2008). Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. *Science*, **322**, 261–264.

Mouratidis, S., et al. (2025). Future biodiversity patterns under climate and land-use change: Evidence from species distribution models. *Ecological Modelling*. https://doi.org/10.48550/arXiv.2511.01122

Myers, R. A., Baum, J. K., Shepherd, T. D., Powers, S. P. and Peterson, C. H. (2007). Cascading effects of the loss of apex predatory sharks from a coastal ocean. *Science*, **315**, 1846–1850.

Pace, M. L., Cole, J. J., Carpenter, S. R. and Kitchell, J. F. (1999). Trophic cascades revealed in diverse ecosystems. *Trends in Ecology & Evolution*, **14**, 483–488.

Palmer, M. A., Lettenmeier, D. P., Poff, N. L., Postel, S., Richter, B. and Warner, R. O. (2009). Climate change and river ecosystems: Protection and adaptation options. *Environmental Management*. https://doi.org/10.1007/s00267-009-9329-1

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

Pearson, R. G. and Dawson, T. P. (2003). Predicting the impacts of climate change on the distribution of species: Are bioclimate envelope models useful? *Global Ecology and Biogeography*, **12**, 361–371.

Pelletier, F., Garant, D. and Hendry, A. P. (2009). Eco-evolutionary dynamics: Introduction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **364**, 1483–1489.

Prütz, R., Rogelj, J., Ganti, G., et al. (2026). Biodiversity implications of land-intensive carbon dioxide removal.

Nature Climate Change, **16**, 155–163. https://doi.org/10.1038/s41558-026-02557-5

Rahmati, Y. (2024). Artificial intelligence for sustainable urban biodiversity conservation. *Sustainability Science*. https://doi.org/10.48550/arXiv.2501.14766

Schipper, J., Chanson, J. S., Chiozza, F., Cox, N. A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A. S. L., Stuart, S. N. and Temple, H. J. (2008). The status of the world's land and marine mammals: Diversity, threat, and knowledge. *Science*, **322**, 225–230.

Sellers, P. J., Dickinson, R. E., Randall, D. A., Betts, A. K., Hall, F. G., Berry, J. A., Collatz, G. J., Denning, A. S., Mooney, H. A. and Nobre, C. A. (1997). Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science*, **275**, 502–509.

Sharma, V., et al. (2024). Assessing climate change effects on India's ecosystems and biodiversity. *International Journal of Innovative Research and Technology*. https://ijirt.org/article?manuscript=185634

Smith, P., et al. (2025). Impacts of climate change interventions on biodiversity, water, food, and human health. *Global Change Biology*, **31**(9), e70444. https://doi.org/10.1111/gcb.70444

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., Siqueira, M. F. D., Grainger, A. and Hannah, L. (2004). Extinction risk from climate change. *Nature*, **427**, 145–148.

Van Buskirk, J., Mulvihill, R. S. and Leberman, R. C. (2009). Variable shifts in spring and autumn migration phenology in North American songbirds associated with climate change. *Global Change Biology*, **15**, 760–771.

Williams, J. W. and Jackson, S. T. (2007). Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and the Environment*, **5**, 475–482.