Impacts of Climate Change on Biodiversity and Ecosystem Services: Direction for Future Research

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Abstract: The potential adverse effects of climate change have posed serious threat to all species of the planet in many ways. Species' functional characteristics strongly influence ecosystem properties. Although significant numbers of studies have already explored the interrelationship between biodiversity, ecosystem services and climate change more focused studies have now begun to appear with the goal of investigating and analysing the negative consequences of climate change on life support systems. This review paper discusses the impacts of climate change on biodiversity and redirects how these losses of biological species on earth have affected and will continue to have effects on the delivery chain of ecosystem services. Concluding section of this paper spotlights on possible mitigation and adaptation plan of actions which contributes in minimizing climate change induced risks while supporting biodiversity and thus the entire ecosystem services. The timeliness of this review is evident because the concerns regarding the potential impacts of global climate change on species and ecosystem services are widely and seriously recognized as major threat of our time.

Keywords: Adaptation, biodiversity, climate change, ecosystem, freshwater, marine, mitigation, terrestrial

Introduction

Global climate change has attracted much scientific and public attention in recent years. Intergovernmental Panel on Climate Change (IPCC) defines climate change as one of the most important factors affecting disaster risk (IPCC, 2013). The United Nations Framework Convention on Climate Change (UNFCCC) defines Climate Change Adaptation (CCA) as the needed modifications in response to the changes in social-ecological and economic systems in relation with climate change (UNFCCC, 1992). Meanwhile, the United Nations International Strategy for Disaster Reduction (UNISDR) defines Disaster Risk Reduction (DRR) as the reduction of disaster risk through causal analysis and management primarily through the cutback of exposure and vulnerability to prevent disaster (UNISDR, 2005). Changing climate is due to unprecedented industrializations and economic activities that results in the release of Green House Gases (GHGs) into the atmosphere (WWF, 2010; IPCC, 2007). Subsequently, this leads to the rise of earth's temperature due to the radioactive properties of GHGs (Lama & Devkota, 2009). As mentioned in the Intergovernmental Panel on Climate Change (IPCC) report, global warming is expected to continue with an increase of 5.8°C by 2100 in comparison to 1.4 °C of 1990 (IPCC, 2007). As a result of increasing temperatures, the changing climate may have a wide range of effects on environmental resources and biodiversity habitats (Lama & Devkota, 2009). Rapidly increasing warming trend over the last few decades has already shown visible and generally adverse impacts on key resources such as land, animal and water (Danovaro, Dell'Anno, & Pusceddu, 2004). Global warming has already altered seasonal climatic pattern (Nepal, 2013), retreated glacier and permafrost and also caused rangeland shifts of wildlife at higher altitudes (Mace, Norris, & Fitter, 2012).

"Biodiversity" is a broad terminology (Moreno & Rodríguez, 2011). One of the widely accepted definitions of biodiversity is the one that is put forward by the International Union for Conservation of Nature (IUCN) which states that "biodiversity is the variability among living organisms from all sources including 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" (IUCN, 2010). Biodiversity is affected by climate change at different levels from low land to high mountains and from small rivers to deep seas. Some species have become extinct while others are endangered. Extinctions can disrupt fundamental ecological processes (Sodhi et al., 2011). In the case of mountain environments, the effects of climate change can be observed through snow cover loss, receding glaciers, melting permafrost and more extreme events such as avalanches and landslides (Nepal, 2013). Similarly, the loss of biodiversity is one of the most significant aspects of global environmental change, given the extent to which it underpins the global economy and human welfare (Martens & Rotmans, 2005). Although threatened and endangered species at vulnerable locations such as in polar region and high mountains have uncertain life or existence, they play major role in controlling and functioning the ecosystems. Plentiful of studies are available over these issues in scientific and climate change literature. Biodiversity plays a significant role at all levels of ecosystem service hierarchy. The Millennium Ecosystem Assessment (MEA) has defined four types of ecosystem services (provisioning, regulating, cultural and supporting) that are provided by the ecosystem functioning (Mace, Norris, & Fitter, 2012). At the global level, the MEA documented that over 60% of ecosystem services were deteriorating or already overused (Mooney et al., 2009), and it has been argued that this situation is being further worsened by the impact of increasing climate change in recent years. Recent climate change has also triggered immigration and extinction processes of biodiversity across the globe. Current climate projections indicate that more ecological change will occur in the coming decades (IPCC, 2013). Species behaviors are altering and disrupting at an excessive rate which we have already seen in the past and this process is continuing at present and may remain in the future. Human driven habitat reduction and fragmentation have been occurring for millennia, leading to reduced local biodiversity and extinctions in many areas (Dawson et al., 2011). The impact of humans on biotic systems on the earth has dramatically accelerated in recent decades. Loss of animal and plant species has a direct impact on the functioning of ecosystems, and hence to their ecosystem service delivery capacity (Mooney et al., 2009). Therefore, the relationship between the biodiversity and ecosystem services is closely associated.

The first half of this paper discusses the bio hysical impacts of climate change on biodiversity and the earth's ecosystems in an integrated way. The second half of the paper provides an account of adaptation approaches in support of biological species at present and future. Towards the end, closing paragraphs suggest for future research need regarding the inter-linkages between climate change, biodiversity and ecosystem services. Explanatory examples are employed and references are cited to support arguments and discussions throughout this paper.

Biodiversity and Ecosystem Services

There has been substantial debate over both the form of the relationship between species richness and ecosystem processes and the mechanisms underlying these relationships (Chapin et al., 2000). Biodiversity provides numerous ecosystem services that are crucial to human well-being (Diaz, 2006). Ecosystem services are the benefits provided by ecosystems to humans that contribute to sustaining life and its quality. The effect of biodiversity on ecosystem services can be direct. For example, humans derive most of their essential foods and fibers from animals and plants, but this should be harvested on the farms not within the natural ecosystems. Ecosystems can also play a central role within the tourism industry, which can be understood as one of the cultural services that the ecosystem provides. In addition, biodiversity can affect the provision of ecosystem services indirectly, through its influence on ecosystem processes that are essential to Earth's life support systems (Dawson et al., 2011). By affecting the magnitude, pace, and temporal continuity, biodiversity influences the provision of regulating ecosystem services. For example, due to the facilitation of ecosystems the pollination and seed dispersal of useful plants, control of agricultural pests and diseases, parameter of climatic conditions appropriate to humans, and the regulation of human health by which energy and materials are circulated are possible (Chapin et al., 2000). Also, by affecting nutrient and water cycling, soil formation and fertility, biodiversity indirectly supports the production of food, fiber, potable water, shelter, and medicines (Diaz et al., 2005). To understand the complexity of these interactions is very important even in the context of modest ecosystem services; however, it is not possible to make prediction over how these processes and interactions transform under changing climatic situations (Mace, Norris, & Fitter, 2012).

Not only all types of ecosystem services are critically affected due to biodiversity loss as the result of climatic changes but continued disruptions over ecosystem succession are also foreseen to be severe in the future.

Impact of Climate Change on Systems Level

Based on the reviews of relevant articles on climate change, biodiversity and ecosystem services, this section discusses the impacts of climate change on biotic species on terrestrial, marine and freshwater systems and correspond their adaptive responses. Climate variability and change have significant effects on the marine, terrestrial, and freshwater systems. As climate continues to change, there seems a consequence for biodiversity shifts. These resulting effects bring changes on the range and distribution pattern of many species such as, their availability, accessibility, and quality of resources upon which human populations depend (Xu et al., 2009). This will have implications for the protection and management of wildlife, fish, and fisheries resources; protected areas; and forests. The migration of species due to disruption and competition from predatory species is already occurring and is predicted to continue to affect marine, terrestrial, and freshwater communities (Wernberg et al., 2011). The populations of iconic wildlife species, such as the polar bear (ursus maritimus), ringed seals (pusa hispida), great white shark (carcharodon carcharias) and blue whale (balaenoptera musculus) will continue to diminish and then disappear as a result of lack in resources they depend on and the critical changes being observed in sea-ice habitat interactions (Harley et al., 2006). The impacts of human-induced climate change are already being seen from Polar Regions to the urban environment, and communities around the world (Wernberg et al., 2011).

A warming climate threatens mountain snowpack, fresh water supplies and hydropower that serve millions of people. Changes in climate and precipitation patterns will impact agriculture and food security. Populations that are already vulnerable in terms of sea level rise and food security are poised for the greatest hardships. Human infrastructure is threatened by a changing climate, such as encroachment of coastlines, stress to the energy grid, and shifting structures as a result of melting permafrost (Parry, 2007).

Impact of Climate Change on Terrestrial Systems

Earth's terrestrial systems have been extensively altered by human activity and climate change. According to a report by the Millennium Ecosystem Assessment, nearly 75% of the Mediterranean and temperate forests have been adapted by human activity whereas five out of thirteen biomes analysed showed 50% conversion on an average among all (Mooney et al., 2009). Climate change may increase drought and the vulnerability of forests to fire. Tropical forest die back could give rise to a positive feedback in the carbon cycle through forest-climate interactions, but currently the magnitude remains uncertain. It is predicted that in the future there will be more conversion in tropical and semi tropical forests and grasslands which carries an abundant number of biodiversity that are significant for water regulation, carbon sequestration, food and timber, and many other ecosystem services (Harley et al., 2006). Tundra and boreal forests which are not suitable for agriculture and therefore not utilized by humans have now been affected by climate change. During the period of 30 years spring leaf unfolding and fruit ripening patterns changed from by 2.5 and 2.4 days per decade respectively (Mooney et al., 2009). The population of land mammals and bird species are also decreasing due to changing climate and environment. About 150 species of birds have been lost in the last 500 years, and at present one in eight species are threatened with global extinction (Mooney et al., 2009). Migration patterns of songbirds are also found to be changing over time. In a study conducted by Buskirk, Mulvihill, & Leberman (2009), over an examination period of 46 years, 78 species of birds were studied where the spring migration was found to be earlier yet the autumn migration seemed unaffected.

Several species of plants, birds and animals have responded to climate change in different manners, some do cope better with changes than others due to their ecology and evolutionary characteristics (Dawson et al., 2011). Lowland species are found to be increasing their elevation distribution whereas high elevation species are adopting restructuring community relationships (Woodward, Perkins, & Brown, 2010). Terrestrial species with good dispersal abilities and wide thermal tolerances are able to shift their distributions but we have seen that the iconic species are being vulnerable because of habitat fragmentation and adverse climatic situation (Mooney et al., 2009). Similarly, global climate change has profound implications for marine ecosystems as well (Harley et al., 2006).

Impact of Climate Change on Marine Systems

Marine ecosystems are of huge importance to the biology of the planet because they are among the largest of earth's aquatic ecosystems and play significant role for the overall health of both marine and terrestrial environments (Townsend et al., 2003). Also, marine ecosystems usually have a large biodiversity and are therefore thought to have a good resistance against invasive species. The changing climate however is having a major adverse impact on marine ecosystems (Brierley & Kingsford, 2009). Given their global importance, coastal marine environments are a major focus of concern regarding the potential impacts of anthropogenic climate change (Wernberg et al., 2011). Current studies have widely discussed that rapidly escalated greenhouse gases concentration at present are driving ocean systems toward the conditions not seen for millions of years in the past, with an associated risk of fundamental and irreversible ecological transformation (Hoegh-Guldberg & Bruno, 2010).

Although there is considerable uncertainty about the spatial and temporal details, climate change is clear and fundamentally altering ocean ecosystems (Harley et al., 2006). Marine ecosystems have been severely affected due to global warming; it has caused habitat destruction and introduced invasive plant and animal species, warming, acidification, toxins and massive runoff nutrients in water (Mooney et al., 2009). Several studies cited in this paper have shown that the population of marine species is sharply declining just in last twenty years. A study conducted by Jackson (2008) in coastal estuaries revealed that 80% of the largest vertebrates such as shark and blue whale, 90% of oysters, 65% of sea grass and 67% of wetlands were lost due to the change in climatic variations and weather patterns. Similarly, another study conducted by Polovina and colleagues (2008) showed that the oligotrophic waters of the ocean expanded by 6.6 million km^2 in the last 20 years, due to global warming.

The term 'benthic' refers to anything associated with or occurring on the bottom of a body of water (Bertness, 1999). The animals and plants that live on or in the bottom are known as the benthos. Benthic systems are important service providers and players to the photic zone and climate regulation (Danovaro et al., 2008). The photic zone is the surface layer of a body of water. It has enough light for organisms to photosynthesize. In the ocean, around 90% of the life can be found in this zone. However, due to the negative effects of climate change on marine systems, the principal ocean derived ecosystem services used by humans such as tourism, fisheries, nursery habitats are all compromised (Mooney et al., 2009). The most influential impact of climate change on the world's oceans are on habitat-forming species such as corals, sea grass, mangroves, salt marsh grasses, and oysters where these organisms form the habitat for thousands of other species in marine ecosystems (Harley et al., 2006). For example, Mega bats (Pteropodidae), which roost in mangroves during the day and fly out at night to forage in surrounding forests. Similarly, mangroves also provide night- time roosts for Pied Imperial Pigeons (Ducula spilorrhoa) that fly to coastal rainforests during the day to feed (Epstein et al., 2009). Coral reef ecosystems are declining because of anomalously warm sea temperatures, which are driving an increased frequency of coral bleaching and mortality. Mass coral bleaching and mortality are results of increasing temperatures that have reduced the richness and density of coral reef fishes and other organisms. These impacts are combined with local impacts such as habitat destruction and food scarcity, in addition to the slowing of reef accretion due to the impact of ocean acidification. Complex coral-dominated reef ecosystems are likely to be declined by 2050 (Baker et al., 2008).

Mangroves, sea grass, and salt marsh communities also face escalating threats from both local and global stresses. Although worldwide mangrove deforestation is occurring at (1 to 2% per year), the risk to mangroves from rising sea levels are increasing. It is expected that there will have been a reduction of between 10 to 20% of mangrove forests by 2100 (Danovaro et al., 2008). Impacts on mangrove habitats vary with location and in many areas they can adapt to rising sea levels by landward migration. However, these shifts threaten other coastal habitats such as salt marshes, which play important biochemical and ecological roles (Satyanarayana et al., 2013). Coral reefs and kelp forests play a significant role in structuring the biodiversity of polar oceans, but due to the effects of global warming, the functional role of marine ecosystems to keep water animals in natural setting is diminishing over time and has been weakened severely. Also, there is a great implication of marine ecosystem services to human beings. Mooney et al. (2009) mark that over 100 million people in six South East Asian countries, known as "Coral Triangle" would face problem of food uncertainty due to sea level rise, loss of coral reefs and calcification.

Impacts of Climate Change on Freshwater Systems

Freshwater ecosystems may well be the most endangered ecosystems in the world. They are biologically rich and play major roles in providing ecosystem services to a greater magnitude (Mooney et al., 2009). Freshwaters are principally vulnerable to climate change because many species within these fragmented habitats have limited abilities to disperse as the environment changes, water temperature and availability are climate-dependent, and many systems are already exposed to various anthropogenic stressors such as contaminants and pollutants and noises (Woodward, Perkins, & Brown, 2010). Freshwaters systems are relatively isolated and physically fragmented within a largely terrestrial landscape. They are also heavily exploited by humans for the provision of goods and services. Studies researching organisms within the freshwater realm suggest that freshwater biodiversity is highly susceptible to climate change. Extinction rates and extirpations of freshwater species either match or exceed those suggested for better-known terrestrial taxa (Heino, Virakkala, & Toivonen., 2009). The degree of alteration of river and lake systems by human is clear. Humans have been exploiting freshwater systems for drinking water, transportation, irrigation, and power generation.

However, proper attention has not been given to other ecosystem services that this system provides, such as temperature regulation, water purification, erosion and flood control and cultural services (Mooney et al., 2009). Several studies are carried out to see and examine the impact of climate change on freshwater systems and ecosystem services. Palmer et al. (2009) mention that half of the world's wetlands have been altered (Nilsson et al., 2005). Over 45,000 dams have been created globally including half of the largest river systems of the world. This has resulted in the modification and loss of flow regime, fish biota and several other freshwater species in the rivers. Construction of dams has disrupted the ecological diversity and function of river systems. It has also altered the level of sediment flux and thermal regimes, among other important physical factors driving ecosystems functioning also suggest that modification of flow regimes has resulted in biotic homogenization of the fish biota of the world (Poff et al., 2007). This has been stimulated by the introduction of fish species favored by the thermal and flow conditions induced by dams.

Many of the development schemes throughout river water courses have led to the drastic losses and damages in the population of freshwater species and riparian zones (Moore & Palmer, 2005). The causes of threats to global freshwater biodiversity can be viewed in terms of over exploitation (primarily affecting vertebrates, e.g. fish, reptiles and some amphibians), water pollution, flow modification, destruction or degradation of habitat, and invasion by exotic species and these causes in the declination of freshwater biodiversity from microbes to mega fauna (Dudgeon et al., 2006). Environmental changes occurring on a global scale, such as nitrogen deposition, warming, shifts in precipitation and runoff patterns are all major threats to freshwater systems (Woodward, Perkin, & Brown, 2010).

Climate Change Mitigation and Adaptation

There are two main strategies for tackling the issue of climate change on biodiversity: 1) mitigation of greenhouse gases, and 2) adaptation to impacts. More importantly, climate change adaptation is an emerging field of research that focuses on preparing for, coping with, and responding to the impacts of current and future climate change (Stein et al., 2013). Human-induced alteration of the global environment has triggered and caused widespread changes in the global distribution of organisms. These changes in biodiversity alter ecosystem processes and change the resilience of ecosystems to environmental change. This has profound consequences for services that humans derive from ecosystems (Chapin et al., 1998). Mitigation is the anthropogenic intervention to shrink the sources or enhance the sinks of greenhouse gases (IPCC, 2001). Similarly, climate adaptation has been defined as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" and "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007, p. 6).

Mitigation

Mitigation activities influence biodiversity (Omann, Stocker, & Jäger 2009). Some of these activities include reducing green house gas emissions through the reduction of fossil fuel use, land based emissions via conservation of existing large pools in ecosystems and increase in the rate of carbon uptake by ecosystems (Kim, 2004). Depending on the design and implementation of strategies such as land use and forestry activities such as afforestation, reforestation and land management practices, as well as the use of renewable energy sources (biomass, wind power, solar power etc.) instead of fossil fuels their temporal and spatial scale, they can have positive, neutral or negative impacts (Omann, Stocker, & Jäger, 2009).

Some of these strategies may lead to loss of biodiversity by substituting rapidly growing tree plantations for diversified forests in order to increase carbon uptake, for example, or by growing bio fuel crops (UNEP, 2007). Another prominent mitigation activity for the reduction of fossil fuel use or enhancing sequestration by sinks is taxes on emissions, carbon and/ or energy subsidies favouring renewable energy sources (Omann, Stocker, & Jäger, 2009). Also by putting (non-) tradable permits, implementing laws and regulations to restrict the use of fossil fuel mitigation strategies can be made more effective (IPCC, 2001). Other activities include lawful provisions of voluntary agreements, technology and performance standards, support of energy efficiency improvement and road pricing (IPCC, 2007). Mitigation policy measures help in stabilizing or reducing atmospheric concentration of greenhouse gases (GHGs) to levels that do not dangerously interfere with the climate system (Kimmel, 2009). Depending on the intended outcome, mitigation approaches can seek to either maintain the persistence of current conditions or facilitate transitions to alternative states (Stein, et al., 2013). Above mentioned are some of the considerable mitigation measures to climate change that support for biodiversity conservation.

Adaptation

In biodiversity and climate change related literature (Bonebrake & Mastrandrea, 2010; Heino, Virkkala, & Toivonen, 2009; Mawdsley, O'Malley & Ojima, 2009; Dawson et al., 2011) discussions over the implication of adaptation measures are widely talked compared to the effectiveness of mitigation measures. Adaptation refers to adjusting or accommodating to climate change-induced impacts, which includes minimizing negative consequences and enhancing opportunities (Njoroge, 2014). Adaptation responses are essentially planned or unplanned policy responses designed to increase the resiliency of our natural, socioeconomic, and built environments (Kimmel, 2009). Planned adaptation to climate change denotes actions undertaken to reduce the risks and capitalize on the opportunities associated with global climate change (Füssel, 2007). Parallel to Njoroge (2014) view that adaptation is becoming an increasingly important public policy response, several national and international authorities, corporations, scientific research institutes, non-governmental organizations and conservation unions are also making significant efforts to identify the possible threats and opportunities of climate change and have recommended for considerable adaptation and mitigation policy measures (Fisher & Slaney, 2013). Hence, an immediate action is required to identify the risks of climate change and imply the adaptive options to cope with such changes in order to ensure the persistence of many species and associated ecosystem services (Heller & Zavaleta, 2009). Scientists have been writing about adaptation with increasing frequency over the last two decades. However, Heller & Zavaleta (2009) suggest that development in this area have progressed albeit at a slow pace. Adaptation is indispensable at present because biodiversity and earth's ecosystems are being more vulnerable due to climatic changes. However, the adaptation activities have to be carefully planned and considered as they require a multidimensional approach (Jones & Phillips, 2009). A broad distinction can be drawn between actions that often involve creating policies or regulations to build adaptive capacity and actions that implement operational adaptation decisions (Barnett & Adger, 2007). Similarly, natural resource managers and policy makers are increasingly incorporating climate considerations into their planning and management, taking advantage of an emerging body of adaptation principles, strategies, and planning processes (Stein et al., 2013). Based on the estimated rate, magnitude, and character of future climatic change, it is predicted that even the most aggressive adaptation actions might not be able to prevent losses of biodiversity or serious degradation of ecosystems and their services as negative effects of climate change exceeds the attempts made for adaptation activities.

Few studies have reported the beneficial effects of global changes on biodiversity. However, there are several factors associated with climate change that potentially could see climatic changes having such positive effects: 1) more clement temperatures, 2) increased CO_2, are likely to be beneficial to many plants, resulting in an acceleration of biomass production, 3) milder winters, which might increase survival of many currently threatened species in temperate regions, 4) increased precipitation which may also benefit some plant communities and species that depend on them (Bellard et al., 2012).

Evidently, adaptation can be perceived in two main ways: autonomous and planned. Species may be able to adapt autonomously to climate change by dispersing to suitable habitats, changing their phenotype without a change in genotype via phenotypic plasticity, adapting by genetic change over generations (Urban et al., 2007). Some species will be able to adapt better than others, depending on generation times, ability to disperse, and dependency on other species, for example pollinators, hosts for parasites and symbionts (Toby et al., 2010). Potential further constraints to evolutionary responses to climate change include time lag between change and response, and erosion of genetic variation (Paterson et al., 2008). It is widely agreed that many species and ecosystems will not be able to adapt naturally to climate change under the time scales predicted, and that planned adaptation responses will be required (Gilman et al., 2008).

Thus, on the face of climate change, adaptation and conservation management activities are pushed to tackle with several challenges, including resolution of the tension between urgency of action and uncertainty about the nature and magnitude of climate change itself in any given location. Similarly, other complexities can be listed as likely responses of species and ecosystems; the effect of the interaction of different responses; and the possible effects of management on responses (Paterson et al., 2008). Relatively there is still some concrete scientific evidence on the effectiveness of different management strategies in relation to climate change, so Stein and colleagues (2013) write that much of the adaptation work is still based on ecological reasoning, rather than on extensive research and case studies. In the face of these uncertainties, there is a necessity of proactive management strategies that can quickly be adapted to new circumstances and changing conservation priorities; these will require institutional coordination, incorporation of climate change scenarios into planning, and efforts to address multiple threats simultaneously (Heller & Zavaleta, 2009).

Scope for Future Research

In order to distinguish the need and best practices for adaptation and mitigation, both global and location-specific research and evaluation activities are required, e.g. projecting current and future climate change impacts, assessing vulnerabilities including climate-related hazards (for effective decisions for climate risk management), evaluating resilience and adaptive capacity; and evaluating current and future adaptation and mitigation activities, including possible new opportunities that may arise from climate change (Carter, 2007). Increasingly, governments, institutions and businesses are taking steps to try and achieve sustainable development, in that they are developing responses to mitigate and adapt to the threats and opportunities of climate change (IPCC, 2007). However, much work remains to be done because there is a serious disconnection between the announcements and commitments made by public policy makers and the actions undertaken by companies regarding how to address the influences of climate change (Sullivan, 2010). This explains that there is a significant increase in the scope of research to study and analyze the impacts of climate change on biodiversity and ecosystem functioning.

As an outline agenda for future research, improvements in our capacity for forecasting species responses to changing climate- for example, by incorporating biotic interactions in bio-climate models and refining species-specific process-based models are required. Other areas include the longstanding scientific challenge of understanding when a given species will become invasive in a given context. Restoration activities have long involved management of disturbance regimes, ecosystem functioning, and species interactions. Adapting to the impacts of climate change requires an active management, including assisted colonization, and other interventions, such as enhancement of evolutionary adaptation, and active maintenance of pre-climate change processes and conditions. Ultimately, one of the biggest challenges for fostering biological adaptation may be willingness across stakeholders, scientists and managers to re-calibrate existing expectations of nature and reserves in responding to an era of global change.

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