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Impacts of climate change on biodiversity

Saeed Sharafi[1*], Parviz Haghighat Jou[1] and Niloofar Alavi Tabaee[2]

1- Zabol University, agriculture faculty, Iran-Zabol
2- Azad University of Birjand, iran

Corresponding author: Saeed Sharafi

ABSTRACT: Considerable biotic changes have occurred globally during these cycles; for the last 11,000 years the Earth has been in a relatively stable warm phase of the cycle and is probably within a degree or two of being the warmest it has been for over 2 million years. At the global level, human activities have caused and will continue a loss in biodiversity. This paper considers the connection between climate and biodiversity. Climate change has synergistic effects with many of the biggest existing impacts to biodiversity. Many studies show that potential climate change impacts on biodiversity through habitat loss and fragmentation, invasive species, Species exploitation and Nutrient enrichment. Distributions tend to shift down temperature gradients. the direction of shifts vary considerably among species depending on which bioclimatic variables are most important in the models for each species (e.g. changes in moisture availability may differ from changes in temperature, and the direction of temperature gradients may alter seasonally), and some species show little or no change.

***Keywords*:** Climate change, Biodiversity, Distribution, Global warming

INTRODUCTION

Climate change is both a cause and an effect of biodiversity change. Along with anthropogenic dispersion, climate change is the main driver of change in the geographical distribution of both beneficial and harmful species crops, livestock, harvested wild species, pests, predators and pathogens. And the capacity of ecosystems to adapt to climate change depends on the diversity of species they currently support. Climate change is also a consequence of the way which biological resources are converted into useful goods and services, and especially of the way in which grasslands and forests are converted into croplands. The production of biological resources for foods, fuels and fibers, and the conversion of forests and grasslands for agriculture both directly affect emissions of several greenhouse gases (GHGs).

In principle, evaluation of the biological causes of climate change requires estimation of the multiple ways in which the production, processing and consumption of foods fuels and fibers are associated with climate drivers emissions of GHGs. Combustion of fossil fuels is the dominant source of CO_2, but agriculture is a major source of CH_4 and N_2O (U.S. Environmental Protection Agency 2010).

Observational studies are also vulnerable to a bias towards more successful publication of observations of significant changes and changes conforming to climate change predictions. While such meta-analyses do not provide species or location-specific information, they do give very powerful information about the extent to which processes that have been predicted are actually occurring, and they can reduce positive-reporting bias by only including multi-species studies or studies with both positive and negative trends.

These changes in climate can impact biodiversity either directly or indirectly through many different impact mechanisms. Range and abundance shifts, changes in phenology/ physiology/behavior, and evolutionary change are the most often cited species-level responses. At the ecosystem level, changes in structure, function, patterns of disturbance, and the increased dominance of invasive species is a noted concern. Having a clear understanding of the exact impact mechanisms is crucial from the perspective of evaluating potential management actions.

This review draws heavily on recent reviews (Hughes 2000 & 2003, Walther 2002, Root *et al*. 2003, Parmesan & Yohe 2003, Lovejoy and Hannah 2005, Parmesan, 2006).

The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that the global atmosphere is warming, noting that the average global surface temperature has increased by nearly 1 ^{o}C over the past century and is likely to rise by another 1.4 to 5.8 ^{o}C over the next century (IPCC, 2001a). The potential for climate change to impact biodiversity has long been noted by the IPCC, other bodies (UNEP/IES, 1998), and by research biologists (e.g., Peters and Lovejoy, 1992). The recent leading book on the subject, *Climate Change and Biodiversity* (Lovejoy and Hannah, 2005) provides a comprehensive scientific overview of both the past and potential future effects of climate change on biodiversity, and explores the associated conservation and management challenges. Climate change has synergistic effects with many of the biggest existing impacts to biodiversity. Many authors in Lovejoy and Hannah (2005) stress concern that potential climate change impacts on biodiversity will be occurring in concert with other already well-established stressors. Specific examples evident include:

1. Habitat loss and fragmentation

With sea level rise, coastal marshes, wetlands, and mudflats may migrate further inland. However, this process will be constrained by built environments (Beckmann, 1997, BC MOE 2006). Here, habitat fragmentation, in the form of dikes, could act synergistically with climate change, reducing and potentially eliminating wetlands and mudflats.

2. Invasive species

Warmer, dryer temperatures in resulting from climate change are less suitable for native plants, and more suitable for invasive species (Scott and Suffling, 2000). Also, invasive species and climate change act synergistically, threatening native species. Changes in the distribution of diseases and disease vectors are problematic because they involve a disassociation between the pathogen and its natural controllers. The disruption of the community of organisms that keeps a pathogen in check allows it to spread rapidly. For the same reason, climate change is expected to increase the frequency with which species across a wide range of taxa are able to spread outside their home range. A recent study of the implications of climate change for the potential invisibility of all terrestrial ecosystems concluded that a high proportion of existing ecosystems will become vulnerable to invasion by species from elsewhere under even moderate climate change scenarios (Thomas and Ohlemüller, 2010).

3. Species exploitation

Synergistic action between commercial harvesting and climate change has already been observed (Bradford and Irvine, 1999). Increases in temperatures are expected to have detrimental impacts on species exploitation (Morrison, 2002). A similar synergistic effect could be expected for other organisms. The result of this is that developing countries are generally more exposed to damaging pests and pathogens (Phelps, 2001).

4. Nutrient enrichment

Nutrient enrichment from agricultural runoff could act synergistically with warming water temperatures due to climate change to enhance eutrophication in freshwater systems. Scott and Lemieux (2005) outline this complex policy dilemma involving the formal definitions of “non-native” or “alien” species, and “historical range”. For example, consider how future changes in climate may increase the potential for some species to expand their range into new or open ecological niches say, northward shifts of species across the US border. On the one hand, these species could be considered as non-native or invasive species requiring active eradication policies. On the other hand, the arrival of new species may in fact signal successful autonomous adaptation by a species into a new climate refuge. What this suggests is that invasive species “impacts” and the potential options for managing them will need to be considered on a case-by-case basis.

This paper considers the connection between climate and biodiversity. The impact of climate change on human wellbeing is measured by the change in ecosystem services caused by climate related change in biodiversity. Similarly, the role of species richness and abundance in climate change mitigation or adaptation is measured by the change in the climate-related services of biodiversity.

Climate change history

About 3 Ma the Earth began further cooling, and since about 1 Ma it has been in the current phases of glacial-interglacial cycles of cold dry periods (approximately 6°C cooler than today) lasting roughly 100,000 years punctuated by rapid (10,000 years) warnings to temperatures similar to the present, followed by gradual irregular cooling and drying. For at least the last 450,000 years the atmospheric CO_2 concentration has cycled synchronously with temperature between 180 ppm (cool min.) and 280 ppm (warm max.), and it may have been within these bounds for 25 million years (Overpeck, 2005). This period has also seen many global and regional temperature fluctuations on the scale of one to a few thousand years, some regional changes associated with changes in ocean currents have been extremely rapid (10°C in a decade) (Overpeck, 2005). For the last 11,000 years the Earth has been in an interglacial (warm and wet) period that has been uncharacteristically stable compared to the previous 450,000 years; and regional differences notwithstanding, the Earth is probably currently within 1-2°C of being the warmest it has been for over 2 million years (Overpeck, 2005) which is about when the genus *Homo* evolved. Over the last several million years sea levels have lowered by up to 130 m during glacial periods and increased by no more than about 6 m above current levels during interglacial periods (Overpeck, 2005).

The plants have experienced considerable climatic changes in the past, including many cycles of warming and cooling over the last few million years. Considerable biotic changes have occurred globally during these cycles; for the last 11,000 years the Earth has been in a relatively stable warm phase of the cycle and is probably within a degree or two of being the warmest it has been for over 2 million years. Without significant reductions in GHG emissions, future climate change in the world will be unlike any previous changes due the extensive fragmentation and modification of habitat by human activities, the presence of exotic species, decreasing (rather than increasing) water availability, and the rate, magnitude and direction of temperature change (Dunlop & Brown, 2008).

In the past, climate change has been associated with massive changes in natural ecosystems and losses of biodiversity. For example, the transformation of Australia from a continent with a substantial cover of Gondwanan rainforests to the driest continent on earth where spinifex grassland is the single most common vegetation type has been as a result of natural climate change over millions of years. More recently Australia has experienced climatic fluctuations that had substantial effects on the distribution and abundance of flora and fauna (Kershaw et al. 2003; Hopkins,1993).

Global impacts of climate change

Since the industrial revolution human-initiated emissions of carbon dioxide (CO2), methane and nitrous oxide have increased markedly leading to increased concentrations of these gases in the atmosphere. These “greenhouse gases” (GHG) reflect radiation back towards the Earth enhancing the natural greenhouse effect. These increases, together with other human-induced changes to the atmosphere, have led to an increase in the average temperature of the Earth’s surface of about 0.76 ± 0.19°C since the late 1800s (Solomon, 2007) and 0.33°C since 1990 (Rahmstorf, 2007). The IPCC Fourth Assessment Report estimates continued increases in atmospheric GHG concentrations would lead to temperature increases between 1.1 and 6.4°C over the 1990 baseline by the end of the century (Solomon, 2007); however recent observations of temperature increases since 1990 are most consistent with increases toward the top of the IPCC range (Rahmstorf, 2007). Along with further increases in average temperature, the Earth will experience changes in the variability of temperature over space and time; changes in rainfall patterns including average amounts and variation; increases in sea temperature, level and acidity; and changes in extreme events such as storms, droughts, fires, floods, and heat waves.

Widespread concern about these impacts has resulted in calls to reduce the rate and magnitude of global climate change by reducing GHG emissions. However, even if emissions were reduced substantially to maintain GHG concentrations at year 2000 levels, temperatures would continue to increase for decades and the global Earth system would continue to change for thousands of years (Solomon, 2007). Climate change will have a wide range of impacts on species and ecosystems, including changes in:

Species distributions and abundances, ecosystem processes, interactions between species, and various threats to biodiversity. Four threats that will be affected by climate change and will be particularly hard to manage due to strong biophysical and social dimensions are: the arrival of new (native and exotic) species in a region, altered fire regimes, land use change and altered hydrology. Differences between species and the complexities of natural ecosystems will lead to uncertainties about the exact nature of change in biodiversity. Key uncertainties concern the dynamics and processes of ecological changes and the role that habitat variability across the landscape plays in mediating changes.

A critical component of conserving species is the availability of suitable habitat. Species and ecosystems will change in their requirements and distributions, therefore ensuring that widespread and diverse habitat is protected in the future will be essential for conserving species (Dunlop & Brown, 2008). Changes to species richness and abundance will affect ecosystem function and ecosystem services (Chapin, 2000; Hooper, 2005).

Globally, there have been significant fluctuations in biomes over the last million years, with forest communities dominating most areas in interglacial periods and herbaceous communities dominating in glacial periods (Huntley 2005). In the Northern Hemisphere these cycles were characterized by major changes in populations of many plant and animal species; during glacial periods the distribution of some species contracted towards the equator up to 2000 km (Huntley 2005). Recent evidence (including genetic analysis) suggests that many species may also have persisted in very restricted populations in micro-refuges (McGlone & Clarke 2005, Rowe, 2004; McLachlan, 2005; Svenning & Skov 2007).

Climate change and ecosystem services

There are few studies considering the effects of climate change on ecosystem services. Schröter, (2005) reported large changes in ecosystem service in Europe from various land use and climate change scenarios; some of the changes were positive (e.g. increased forest area and productivity) and others negative (declining soil fertility and water availability). Many individual impacts are possible including impacts on human health through periods of thermal stress, air pollution impacts, impacts of storms and floods and infectious diseases (IPCC 2001). Positive and negative impacts on productivity of cropping, grazing and forestry are expected (Kirschbaum 1999; Reyenga, 2001; Howden, 2003; Pittock 2003; Steffen and Canadell 2005); these activities will also be affected by changes in plant diseases (Chakraborty, 2000). Recent impacts of drought and cyclone damage in Australia demonstrate the sensitivity of agriculture and the economy to climate.

Ecosystems are a fundamental part of the Earth System that includes the dynamics and chemistry of the atmosphere, soils and the oceans (Betts & Shugart 2005). Biodiversity is one of the ecosystem services that affected by climate change. There is widespread recognition that climate change and biodiversity are linked. Most obviously, by changing the environmental conditions within which species exist, climate change induces an adaptive response on the part of species. An extensive literature over the last two decades has described this effect on both species and ecosystems (Peters and Lovejoy 1994, Lovejoy and Hannah 2006, Willis, 2003). Much of this is summarized in the international biodiversity and climate assessments at various scales (Gitay*,* 2002, Steffen*,* 2010, Karl*,* 2009, Millennium Ecosystem Assessment 2005a, Millennium Ecosystem Assessment 2005b).

Many positive and negative feedbacks in the Earth System have been observed and hypothesized; for example, enhanced uptake of CO_2 by terrestrial plants, emission of methane from drying peat lands, changed fire regimes, altered aerosol initiation, altered albedo from changed land cover (including melting of icecaps) (Steffen *et al*. 2004; Betts & Shugart 2005).

Ecosystems and biodiversity have significant cultural, intellectual, aesthetic and spiritual values that are important to the human society as well as providing more tangible ecosystem services critical to the productivity of economies and the maintenance of human societies (Daily 1997; Chapin, 2000; Abel, 2003; MEA 2003).

Evaluation of the impacts of climate change on biological resources and biodiversity requires estimation of the consequential changes in the production of ecosystem services. This includes changes induced by alteration of environmental conditions reflected, for example, in the changing costs of agriculture, forestry and fisheries. It also includes changes in a set of non marketed ecosystem services. The assessment of the economics of ecosystems and biodiversity (TEEB) has addressed the problem of identifying the biodiversity mediated impact of climate change by developing a database of valuation studies, and reporting the distribution of the estimated values associated with the ecosystem services affected by climate change. It is not the purpose of this paper to review this material. It is sufficient to note that the value estimates reported are marginal, instrumental, anthropocentric, individual-based and subjective, context and state-dependent (Goulder and Kennedy 1997, Heal*,* 2005).

To estimate the value of climate-related biodiversity change, we need to understand:

(a) The impact of land use change on climate and the other structural characteristics of the system that affect biodiversity,

(b) The effect this has on the functional diversity of species, and

(c) The consequences of change in the functional diversity of species for the ecosystem services that people care directly about such as the supply of foods, fuels and fibers, pharmaceuticals, scientific information, genetic resources, recreation, tourism, amenity and spiritual satisfaction (Tol, 2002).

In fact, the key climate-related ecosystem services supported by biodiversity are all regulating services, whose importance depends in part on the value at risk and in part on the factors threatening that value. They include:

• Macroclimatic regulation (through carbon sequestration and the management of albedo effects)
• Microclimatic regulation (through local canopy effects)

• Hydrological regulation (mitigation of the hydrological impacts of climate change through watershed protection)
• Soil regulation (mitigation of the consequences of climate change for erosion through vegetation cover)
• Maintenance of adaptive capacity (through in situ conservation of the diversity of functional groups including land races and wild relatives).

All these services are also jointly produced with provisioning, cultural or supporting services. In fact, it is a characteristic feature of ecosystems, that the biodiversity each supports offers an array of benefits at quite different spatial and temporal scales (Perrings and Gadgil, 2003).

Changes in phenology

Climate has a major influence on rates of photosynthesis and respiration (Woodward, 1995, Kueppers, 2004, Law, 2007), and on other agroecosystems processes, acting through temperature, radiation, and moisture regimes over medium and long time periods. Climate and weather conditions also directly influence shorter-term processes in agroecosystems, such as frequency of storms and wildfires, herbivory, and species migration (Gundersen and Holling, 2002). As the global climate changes, agroecosystems will change because species' physiological tolerances may be exceeded and the rates of biophysical ecosystems processes will be altered (Olesen, 2007, Kellomaki, 2008, Malhi, 2008).

The timing of lifecycle events in many species is often related to temperature, thus increases in temperature are expected to lead to changes in timing. The most likely changes are advances in spring events and delays in autumn events; shortening of various life-stages are also expected. Such changes have been observed in many species in the Northern Hemisphere, including herbs, shrubs, trees, insects, birds, amphibians and fish (reviewed in Hughes 2000; Fitter & Fitter 2002; Walther, 2002; Parmesan & Yohe 2003; Root, 2003; Parmesan 2006).

Climate change and biodiversity modeling

A wide variety of methods have been used to model changes in the distribution of biodiversity as a result of climate change. The main differences are between: modeling individual species and modeling groups of species (functional types, communities, ecosystems or biomes); and between: modeling species' observed environmental niche and modeling ecological or physiological processes. Some models use a mixture of approaches. Also important are the aspect of the distribution that is modeled (presence/absence, abundance, probability of presence, or species richness), the type of observation data used (presence only or presence/absence data, and with or without planned sampling), and the process used estimate environmental niches (e.g. bioclimatic range, statistical fit, artificial neural networks, genetic algorithms). There are also variations in the implementation of each approach; and analyses vary in the extent to which the models they use have been validated. Recently a number of studies have assessed various bioclimatic modeling methods (e.g. Thuiller 2004; Araújo, 2005; Araújo & Rahbek 2006; Elith, 2006; Pearson, 2006). They also show considerable variation among models in their ability to predict current distributions; and more recently developed methods appear to have better performance (e.g. Elith, 2006). The BIOCLIM model has repeatedly been shown to perform poorly compared to other models (e.g. Elith, 2006; Pearson, 2006); as such, its results should be used with great caution. There appears to be a trade-off among some models between precision of fit (in a region) and generality (between regions) (Araújo, 2005; Araújo & Rahbek 2006). Models of species with small distributions tend to be less accurate (Schwartz, 2006), and bioclimatic models generally appear to be more accurate at coarser scales (Pearson & Dawson 2003). Araújo, (2005) compared predicted distribution changes with observed distribution changes over about 20 years. They found "good to fair predictive performance" in a statistical sense but not necessarily in "decision-planning context"; a poor correlation between the ability of models to fit present and future distributions; and validation on random sub-sample data overestimates model performance. Uncertainty in the digital elevation models that underpin many bioclimatic models (Van Niel & Austin 2007) and in the climate models used (Beaumont, 2007) can significantly affect model results.

Conclusion

Since climate change is expected to increase the variance in temperature and precipitation to the point where environmental conditions that are now extremely rare become commonplace, keeping the crop genetic diversity, the pest predators, the pathogen controllers, and the watershed protectors in place provides insurance in conditions when commercial cover may fail. As agriculture becomes increasingly homogenized, for example, so the spatial correlation of agricultural risks increases, while the capacity to pool those risks reduces.

Many studies show considerable distribution shifts and contractions for many species, and both of these changes give rise to concerns about the persistence of species. In general, distributions tend to shift down temperature gradients (to cooler climes). However, the direction of shifts vary considerably among species depending on which bioclimatic variables are most important in the models for each species (e.g. changes in moisture availability may differ from changes in temperature, and the direction of temperature gradients may alter seasonally), and some species show little or no change. As well as the direction of change, there is variation among species in the rate of modeled distribution shifts. There is also variation among species in the size of their modeled future distributions: some expand, some don't change, and some contract and the distributions of some species are projected to disappear completely under some scenarios. The most consistent result is that there is likely to be considerable variation among species in the responses of their distributions (Thomas, 2004).

Also many studies have predicted that actual species migration rates may be less than is required for species to remain within their shifting bioclimatic envelopes (e.g. Malcolm, 2002), and that habitat fragmentation may limit migration (Higgins, 2003). Others have shown that species interactions and rates of long distance dispersal may be very important in determining distribution shifts, and that long distance dispersal can greatly reduce the importance of habitat connectivity (Pearson & Dawson 2005; Brooker, 2007).

Many commentators have raised concerns that species might not be able to migrate fast enough to track shift in their core bioclimatic habitat (Malcolm, 2002; Lovejoy and Hannah 2005; Ibáñez, 2006). This raises questions about how fast species distributions can change. Many species can clearly disperse long distances rapidly (e.g. many weeds and flying animals), but how fast can tree distributions shift?

Many studies provide evidence that species have expanded their range polewards and upwards in elevation in response to climate warming (Parmesan, 2006). This has been particularly evident in the case of species that can disperse easily, such as birds and strong flying butterflies. In a meta-analysis study covering a wide variety of more than 1700 species, more than half displayed statistically significant changes in range in the direction predicted by regional changes in climate (Parmesan and Yohe, 2003). Species that are not easily dispersed will respond more slowly to climate change, likely resulting in range contractions and reduced abundances. Ample evidence now exists that upper and lower temperature and precipitation thresholds are a strong determinant in the abundance of wild species. As the geographic range of these thresholds shifts, so too will the local abundance of many species (Root and Hughes, 2005).

Plant responses to climate change

Responses to climate change can be divided into two aspects:

1. Mitigation; the term used to describe the process of reducing GHG emissions that contribute to climate change. It includes strategies to reduce GHG emissions and enhance GHG sinks.
2. Adaptation; is a process, or set of initiatives and measures, to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Adaptation can also be thought of as learning how to live with the consequences of climate change. The first consequences of climate change can already be seen in worldwide, and these impacts are predicted to intensify in the coming decades. Temperatures are rising, rainfall patterns are shifting, glaciers are melting, sea levels are getting higher and extreme weather resulting in hazards such as floods and droughts is becoming more common.

Climate change adaptation and mitigation are closely interrelated. While they are often considered as separate topics or policy fields, it is critical to consider the links between them. Certain adaptation responses have clear mitigation benefits, but some actions can result in 'maladaptation' i.e. instead of reducing vulnerability to climate change, they actually increase it or reduce the adaptive capacity. Some actions can also distribute the benefits of adaptation unequally across society (for example, the prevention of climate-change-induced diseases only for affluent people) (EEA, 2010).

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