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Effects of climate change on global biodiversity: a review of key literature

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Abstract: There is very little doubt among the scientific community that human-induced greenhouse gas emission has contributed significantly to the climate change. Most significant changes in the earth's temperature have been noticed since the advent of the industrial era in the late 1800s. Over the past 100 years, the earth's surface has warmed by approximately 0.6°C. Human activities such as the large-scale burning of fossil fuels to operate power plants and automobiles are releasing greenhouse gases like CO_2 into the atmosphere at an unprecedented rate. Humans are currently releasing 70 million tonnes of CO_2 per day into the atmosphere. This paper draws from the major papers that have appeared in journals on this topic over the past two decades, and gives an overview of anthropogenic climate change and its impact on a wide variety of life-forms in various ecosystems. After a brief overview of climate change and its causes, focus is given to amphibian extinctions in Central America, the poleward and altitudinal shifts in the distribution of various organisms (especially butterflies), the spread of pathogen-driven diseases, the bleaching of coral reefs, and the changes in community and trophic dynamics in various marine and terrestrial ecosystems.

Resumen: Hay pocas dudas en la comunidad científica de que las emisiones de gases de efecto invernadero inducidas por los humanos han contribuido significativamente al cambio climático. Los cambios más significativos en la temperatura de la tierra fueron notados desde el advenimiento de la era industrial a finales del siglo XIX. Durante los últimos 100 años la superficie de la tierra se ha calentado aproximadamente 0.6°C. Las actividades humanas como la quema a gran escala de combustibles fósiles para el funcionamiento de plantas de energía y de los automóviles están emitiendo a la atmósfera gases de efecto invernadero como el CO_2 a una tasa sin precedentes. Actualmente los seres humanos están lanzando a la atmósfera 70 millones de toneladas de CO_2 cada día. Este artículo se basa en los principales artículos publicados en revistas sobre este tema en las última dos décadas, y proporciona un panorama del cambio climático antropogénico y su impacto sobre una amplia variedad de formas de vida en varios ecosistemas. Después de una breve revisión general sobre el cambio climático y sus causas, el trabajo se enfoca en las extinciones de anfibios en Centroamérica, los desplazamientos en la distribución de varios organismos hacia los polos y hacia altitudes mayores (especialmente de mariposas), la expansión de enfermedades causadas por patógenos, el blanqueamiento de los arrecifes coralinos y los cambios en las dinámicas comunitaria y trófica en varios ecosistemas marinos y terrestres.

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Resumo: Há muito pouca dúvida entre a comunidade científica que a emissão de gases de estufa, induzida pelo homem, contribuiu significativamente para a mudança climática. Muitas das mudanças significativas na temperatura da terra foi referenciada desde o advento da era industrial nos fins de 1800. Nos últimos 100 anos, a superfície da terra aqueceu aproximadamente 0,6°C. As actividades humanas, tal como a queima de combustíveis fósseis em larga escala para funcionamento das unidades de geração de energia e automóveis, estão libertando para a atmosfera gases de estufa como o CO_2 a uma taxa sem precedentes. O homem está presentemente a libertar na atmosfera 70 milhões de toneladas de CO_2 por dia. Este artigo está elaborado com base nos principais artigos publicados sobre este tópico durante as últimas duas décadas, e elabora uma revisão das mudanças climáticas de origem antropogénica e sobre o seu impacte numa grande variedade de formas de vida em vários ecossistemas. Depois de uma breve revisão das mudanças climáticas e das suas causas, é dado enfoque à extinção de anfíbios na América Central, as mudança em direcção ao pólo e em altitude na distribuição de vários organismos (especialmente as borboletas), a expansão de doenças induzidas por patogénos, o branqueamento dos recifes de corais, e as mudanças nas comunidades e nas na dinâmicas tróficas em vários ecossistemas marinhos e terrestres.

Key words: Amphibian extinctions, coral reefs, global warming, greenhouse gases, marine ecosystems, terrestrial ecosystems.

Introduction

There is very little doubt today among the scientific community that anthropogenic, or human-induced, greenhouse gas pollution has contributed significantly to the global warming (climate change) experienced since the beginning of the industrial era in the late 1800s (Houghton *et al.* 2001; Santer *et al.* 2003). Over the past 100 years, the earth's surface has warmed by approximately 0.6°C (Walther *et al.* 2002). Human activities such as the large-scale burning of fossil fuels to operate power plants and automobiles are releasing greenhouse gases like CO_2 into the atmosphere at an unprecedented rate. We currently are releasing 70 million tonnes of CO_2 per day into the atmosphere. Greenhouse gases are so named because they trap heat and impede its radiation back into the atmosphere, much like the glass panes on a greenhouse does, thus causing a rise in surface temperatures on earth. The already documented very dramatic and sudden rise in earth surface temperature through the 1900s and beyond is shown graphically in the monographs by Cicerone (2006) and Linden (2006).

Scientists warn that if the current rate of greenhouse gas emissions continues, global air temperatures could rise between 1.5 to 4.5°C by the year 2100 (Houghton *et al.* 2001). The direct and more tangible consequences for human civilizations of such a temperature increase range from melting of glaciers and polar ice caps and the subsequent rising of sea levels and flooding of coastal areas, to increase in transmission of tropical diseases, to large-scale disruptions in global climatic patterns resulting in both unusual droughts and flooding world-wide. Carbon dioxide levels (which have been clearly tied to temperature increases) were under 300 ppm (parts per million by volume) for the past 600,000 years (Cicerone 2006; Gore 2006; Revkin 1992). The levels touched 300 ppm for the first time in the 1900s and have been steadily increasing since then. Levels currently have passed at an all-time high of 360 ppm, now are approaching 385 ppm, and are expected to reach 550 ppm by the year 2100 if current rates of emissions continue (Cicerone 2006; Gore 2006; Revkin 1992). The worst case scenario predicts that by year 2100 levels could reach as unimaginably high as 1,000 ppm. Clearly, we are headed for a CO_2-rich world with all its deleterious consequences, and are faced with the morally obligatory task of mitigating these levels by controlling greenhouse gas emissions.

Climate change is not new, and species have traditionally responded to such change over evolutionary timescales. But the key question today is how will organisms respond to the current apparently rapid rate of anthropogenic climate change (Root *et al.* 2003; Round & Gale 2008). This review focuses on the impact of such climate change on global biodiversity and it draws from the wide body of scientific evidence that has accumulated over the past few years. It is intended for students and the lay public to inform them that global warming is a real and growing problem that threatens the existence of human and other life forms. The article takes the readers on a tour of the planet and highlights what global warming has done to a variety of life forms. We highlight some case studies at the individual and population levels and also present some studies that have done some meta-analyses of data to discern a globally coherent fingerprint of global warming across a suite of taxa.

Strong evidence of extinctions due to global warming from Costa Rica: Amphibians raise the alarm

In the mountain forests of Central America, strikingly colored Harlequin frogs (*Atelopus* sp.) were the first charismatic conspicuous vertebrates to succumb to global warming. Sixty-seven percent of 110 endemic species have become extinct in just two decades (Blaustein & Dobson 2006; Pounds *et al.* 2006). A pathogenic Chytrid fungus, which produces aquatic flagellated zoospores, was implicated in this large-scale demise of the frogs. The fungus infects the skin and causes widespread disease among amphibians. Chytrids were first discovered as pathogens in distant Africa in the 1930s, among African-clawed frogs (*Xenopus*). Unfortunately, global trade of *Xenopus* peaked in the 1950s because of the use of *Xenopus* tissue in pregnancy tests, and that is how the fungal pathogen is thought to have colonized the New World (Blaustein & Dobson 2006).

But why did it take nearly three decades for the Chytrids to seriously affect Central American frog populations? Prior to the 1980s the Chytrids did not make serious inroads into frog populations. Pounds *et al.* (2006) made the connection between global warming over the past 20 years and the fungal pathogen in decimating the amphibians. They demonstrated that human-caused climate change induced by global warming has altered transmission rates of the pathogen and thus has led to widespread population declines and local extinctions. Using long-term meteorological and climate data, these authors showed that global warming has increased daytime cloudiness in the mid elevations and thus has resulted in decreased daytime temperatures. At the same time, the increased cloud cover reduced heat loss at nights and thus resulted in night-time warming. This reduction in range of temperatures, they showed, has favored Chytrids because the range fell right within the optimum range for the growth, reproduction and transmission of the fungal pathogens.

Owing to the fact that global warming made it conducive for Chytrids in mid elevations to thrive, mid elevations witnessed the maximum number of species extinctions. Unfortunately, the greatest diversity of frogs existed in mid elevations and this resulted in a double jeopardy for the frogs: the region with the highest species richness suffered the most, and hence the plethora of extinctions. This contradicted previously held assumptions that high elevations would suffer the most under projected global warming scenarios. Pounds *et al.* (2006) further showed that the optimal range for the pathogen is between 17-25°C; at around 30°C, the Chytrids die. Harlequin frogs in the lowlands (0-1,000 m) did not suffer as much extinctions because daytime (maximum) temperatures were too hot (>25°C) for Chytrids; similarly, most higher elevation (>2400 m) frog species escaped extermination because minimum temperatures were below the optimal range (<17°C) for the fungi.

The case of the Central American frogs reinforced long-held fears that global warming can increase the transmission rates of pathogen driven diseases. Other problems forecasted with increased global warming are the pole-ward or altitudinal shift in the ranges of many species, and the advancement of spring phenological events in life histories of various organisms. Such evidence poured in from various other corners of the world, some of which are mentioned below:

Evidence from the United Kingdom

With earlier onset of warm temperatures in spring, many organisms advanced spring lifehistory activities significantly earlier than before. Eighteen butterfly species advanced their spring appearance dates by 2.8-3.2 days per decade over the past 23 years (Roy & Sparks 2000; Walther *et al.* 2002). Amphibians did the same, but not all species responded the same. Predatory newts entered ponds earlier than before, but some traditionally early breeding frogs did not, and hence they suffered increased predation from newts (Beebe 1995; Walther *et al.* 2002). Such differential responses to global warming are expected to alter community and trophic dynamics in various other food webs.

Several species of birds arrived earlier than they did in pre-warming times. Spring first-time migratory arrivals advanced an average of 1.3 to 4.4 days per decade; and subsequent breeding activities too hastened by an average of 1.9 to 4.8 days per decade over a time frame of 30-60 years (Walther *et al.* 2002). Over a span of 25 years, 20 species of birds were recorded to lay eggs significantly earlier than they did before (Crick *et al.* 1997; Crick & Sparks 1999). In the "business as usual" scenario of global warming gas emissions (i.e., if current rates continue unmitigated) it is predicted that the average egg laying dates will be even earlier for 75% of avian species by the year 2080 (Crick & Sparks 1999). The consequences of such early breeding can be varied. If not synchronized with prey abundance, such early breeding could result in decreased lifetime reproductive success and recruitment rates.

Northward shifts in bird species ranges occurred as predicted. Twelve species of U.K. birds have shifted their ranges by an average of 18.9 km over the past two decades, even after controlling for overall population expansions (Thomas & Lennon 1999).

Evidence from Europe

Early arrival in the spring of migratory birds has resulted in increased competition for optimal nest sites with early nesting resident species (Both & Visser 2001). Birds in Europe and the western Palearctic are laying eggs earlier (Both *et al.* 2004; Sanz 2003). In Great Tits (*Parus major*) it was shown that global warming is associated with jeopardized synchrony between prey availability and a critical phase of breeding phenology. Peak dates of caterpillars (a chief prey for tit hatchlings) have been shifted much earlier than the hatching of tit chicks, and this has led to food deprivation for the chicks thereby affecting reproductive success and population recruitment (Visser *et al.* 1998; Visser & Holleman 2001; Walther *et al.* 2002).

Several butterfly species have shown marked northward shifts in ranges in association with northward warming. For thirty-eight species (in Europe and North America), the shift in range has been up to 200 km over a span of 27 years (Parmesan 2003; Parmesan *et al.* 1999; Walther *et al.* 2002). Such poleward shifts in distributions have been reported for a wide variety of taxonomic groups (Hickling *et al.* 2006).

The evidence has mounted from the plant kingdom as well. Flowering and leafing among several European plant species has occurred earlier in the year by an average of 1.4-3.1 days per decade in a study covering a time period of 30-48 years (Menzel & Estrella 2001; Walther *et al.* 2002). Treeline on mountain slopes have moved up significantly (Kullman 2001; Meshinev & Kolera 2000). Alpine plants too have displayed this trend. Some species have shifted upwards in elevational distribution by an average of 1-4 m per decade (Grabherr *et al.* 1994; Walther *et al.* 2002). Even lichens (in Netherlands) have shown long term responses to global warming (Parmesan & Yohe 2003; van Herk *et al.* 2002).

Global warming can affect community composition by encouraging invasion by exotic species. A remarkable study from Switzerland has documented how the drastic reduction in the number of frost days has lead to a consequent increase in the number of exotic evergreen broad-leaved plants in a landscape that was originally predominantly deciduous (Walther 2000; Walther *et al.* 2002). In the marine environment, warm water species of plankton have increased in areas that previously had few of them (Nehring 1996).

Evidence from North and Central America

Arrival dates of short-distance migratory birds in North America seem to have been affected disproportionately by global warming (Butler 2003). Dunn & Winkler (1999) reported that climate change has affected the breeding date of tree swallows throughout the continent. In Canada, warming trends have resulted in a northward expansion of the range of the red fox, and a subsequent retreat of the range of the Arctic fox (Hoffman & Parsons 1997; Walther *et al.* 2002).

The Edith's Checkerspot Butterfly (*Euphydras editha*) of western United States has also shown such an expansion. The species has been reported to have experienced a 124 m upward elevational and a 92 km northward shift since the beginning of the 20th century (Parmesan 1996; Parmesan *et al.* 1999). More populations of this species have become extinct in southern latitudinal bands than in northern latitudinal bands. Such range expansions may not be possible for species (like the Florida Panther and several sedentary species in that state's Everglades National Park) whose habitats are hemmed in by development (Revkin 1992).

One of the more pronounced evidences in the North American continent and elsewhere is the increased abundances of warm water species such as some zooplankton, plus jellyfish and other cnidaria, and some reef fishes in areas where they were relatively rare e.g., the Monterrey coast of California (Parmesan & Yohe 2003; Sagarin *et al.* 1999). Jellyfish, in particular, have become a nuisance because of burgeoning numbers (Gore 2006), as they tend to get sucked up power plant cooling systems and have proven to be a menace for beach bathers in many parts of the world.

Shifts in ranges have been reported from the tropics too. All tropical rainforest areas have warmed significantly by an average of 0.26 ± 0.05°C per decade in synchrony with the warming of the earth (Malhi & Wright 2005). Lowland birds in Costa Rica have extended their altitudinal distributions from mountain slopes to higher elevations, largely attributable to anomalies in dry season mist frequencies induced by warming temperatures (Pounds *et al.* 1999).

Evidence from tropical Asia

Evidence is scant thus far from the Asian tropics. Round & Gale (2008) reported changes in the status of *Lophura* pheasants in Khao Yai National Park, Thailand, using a 25 year sequence of records, and hypothesized that this may be a response to a warming climate. Corlett & LaFrankie (1998) believe that most of the plants in the tropical Asian region are adapted to avoid serious phenological consequences due to climate change. Predictive simulation models do show up to a 5°C rise in surface temperature in the region by the mid 2000 (Revkin 1992) and has already increased 1°C in the past 50 years (Cicerone 2006). It is also predicted that places in the tropics, especially all of India, will receive progressively more rainfall than presently (Revkin 1992) resulting in increased frequency in episodes of flooding. Markham (1998) adds to this that evidence suggests the possibility of increased severity and frequency of storms in tropical environs.

Evidence from Antarctica

With the melting of large areas of the Antarctic ice shelf, more liquid and warmer water is available for colonization, and therefore, several Antarctic plants and invertebrates have shown striking distributional changes (Smith 2001). Macroscopic plants like mosses have especially been influenced by the change in climate. But perhaps the Antarctic phenomenon that has not only regional but also global effects is the drastic reduction in population of krill (*Euphausia superba*) in the seas near that continent (Loeb *et al.* 1997). Reduction in sea ice area near the Antarctic peninsula has affected krill recruitment rates. With Antarctic krill being a prime staple diet for numerous oceanic species (including whales) this reduction in krill numbers could have profound effects on the regional food web and subsequently on human economics.

More evidence from the oceans

One of the most destructive effects in association with global warming is evident in the coral reefs of the world's oceans (Glynn 1991; Hoegh-Guldberg 1999; Mumby *et al.* 2001). Coral polyps face retarded growth and reproductive rates in an increasingly warm world. But in addition to that, elevated CO_2 levels increase acidity of the oceans by dumping more carbonic acid into the waters (Gore 2006). Of the 70 million tonnes of CO_2 released per day into the atmosphere, 25 million tonnes are soaked up by the oceans and converted into carbonic acid. This increasing acidification has made it difficult for coral polyps to capture calcium from the waters. These polyps need the calcium to make calcium carbonate, a chief ingredient in shells of marine invertebrate organisms. Coral reefs, therefore, face bleaching (whitening and death as a result of death of the algal symbionts and the polyps) at large-scale levels.

Recent reports showed the gravity of this problem (Gore 2006; National Geographic 2007). Areas with optimal conditions for calcium uptake has shrunk precipitously in the world's oceans in the past two decades, and it is estimated that with all the acidification such favorable areas can virtually vanish by the year 2050, leading to mass extinctions of not only coral polyp species but the entire coral reef ecosystem and its phenomenally high biodiversity.

Coral reefs are especially sensitive to even miniscule amounts of warming. An increase in long-term summer water temperature averages in the tropics by 1.0°C for several weeks is enough to trigger mass bleaching (Walther *et al.* 2002). There have been six such mass bleaching events since 1979, and the frequency and intensity of mass bleaching has increased as temperatures increased. The worst was in 1998 when an estimated 16% of the world's reef building corals died (Gore 2006), mostly attributed to the loss of dinoflagellate symbionts.

Global warming could directly affect human fishery industry. Variations in atmospheric air circulation over the Bering Sea impede the movement of juveniles away from adults of a commercially and ecologically vital species of fish, the Walleyed Pollock (*Theragra chalcogramma*) (Cushing 1995). This makes the juveniles increasingly vulnerable to cannibalism. Considering the fact that Pollock is an important forage fish for a wide variety of mammals (including people) and birds, negative consequences to the entire food web may be inevitable.

It's not only the Pollock that face the problem of global warming, but similar climate-induced changes in prey abundance has affected the migration and spatial distribution of other pelagic fish like Bluefin Tuna (*Thunnus thynnus*) (Polovina 1996), which is one of the world's most sought-after table fish species for people.

Global warming increases the frequency and intensity of oceanic upwelling, a phenomenon in which nutrients from the bottom are periodically brought up to surface waters (McGowen *et al.* 1998). Such natural upwelling is excellent for many wildlife species in the marine ecosystems (such as the coasts of Peru, which is known for its abundant marine life). But the increased upwelling is feared to precipitate a global fish production decline "due to reduction in the concentration and retention processes" (Walther *et al.* 2002).

Global warming along with human overexploitation can exacerbate the situation of depleted fish stocks. Another species of commercially and ecologically important fish, the North Sea Cod (*Gadus mohrua*), faces such a "double jeopardy" situation. The cod's long adult life span usually buffers it against times of poor recruitment, but over-harvesting of adult fish by people has increased the vulnerability of the species to population crashes in face of climate change (Plancue & Fredou 1999; Walther *et al.* 2002).

Prospects and solutions

From the above it is apparent that all regions of the planet earth in some ways are being adversely affected by the global warming trend. If corrective measures are not adopted, the undesirable consequences are admirably expressed in the monograph "Global Warming: Understanding the Forecast" (Revkin 1992). In that publication models of temperature change on a global scale, in the absence of mitigating measures, show striking increases in temperature starting in the past and extending into the future. The average temperatures in tropical biomes are shown to increase by 5 degrees Celsius from the mid 1960s to 2050. The culprits in this global heating scenario are the so-called greenhouse atmospheric gases that capture heat (principally carbon dioxide and methane), which are generated in profusion through the activities of people.

Solving the problem also is well stated in the publication cited above (Revkin 1992) in describing measures required to reduce the emission of the greenhouse gases. Most of the corrective measures pertain mainly to the industrialized world, such as developing alternate sources of energy rather than depending heavily on fossil fuels, or manufacturing more petrol efficient automobiles, to name a couple of actions. In tropical biomes the big issue is preserving ecosystems that absorb atmospheric carbon dioxide. This measure would encourage the cessation of rampant clearing of tropical forests for conversion to agricultural production. Also in this regard, adopting programs to invigorate reforestation in formerly cleared but unproductive lands would be a stellar activity. As nations within the tropical biomes become progressively industrialized, there too, energy sources and means of transportation will become significant issues.

The current seriousness of the situation is found in the statement that noted there have been "28,586 significant biological changes" reported in terrestrial ecosystems associated with climate change (Richardson & Poloczanska 2008). This total does not include the many supporting chronologies from glacial and polar cap studies, or the evidence from investigations in the marine environment.

Conclusions

It is clear that global warming has started negatively affecting a wide variety of organisms world-wide. Extinctions have started, and many organisms are being pushed closer to extinction or local extermination as a direct or indirect result of climate change. Since this is a problem that has been created by humans, it behooves us to solve it. It is morally reprehensible if we do not. In the words of Professor E. O. Wilson, "The loss of species is the folly our descendants are least likely to forgive us". So for the sake of posterity and for the very future of our planet's biodiversity, let us curb greenhouse gas emissions and mitigate the threat of global warming.

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