Climate change and biodiversity

T. Lovejoy

The H. John Heinz III Center for Science, Economics and the Environment, 900 17th St., N.W. (Suite 700), Washington, DC, 20006, United States of America

Summary

There is already widespread change in the natural calendars (phenology) of plants and animals, as well as change in some species distributions. Now threshold change (sudden, fundamental change) in ecosystems is beginning to be observed in nature. At minimum, the natural world will experience an equal amount of warming to that which has already taken place. This all suggests a future with nature and ecosystems very much in flux with profound implications for epidemiology.

Keywords

Climate change – Ecosystem – Land use change – Ocean acidification – System change – Threshold change.

Introduction

The etiology of diseases, whether of humans or other species, is rooted in the fundamental ecology of the disease agent in particular. As a consequence, a general understanding of the potential impact of climate change on species and ecosystems is fundamental to understanding potential impacts on epidemiology.

The temperature record for the planet over the last 100,000 years (Fig. 1) reveals two very important points (5). One – shown by the first 90,000 years – is that abrupt climate change is in fact the normal situation, notwithstanding all existing models being linear and gradual. The second point is that for the last 10,000 years the climate has been unusually stable. That period includes all recorded history, a significant fraction of unrecorded history, the origins of agriculture and the origin of human settlements. The entire human enterprise rests on the assumption that a stable climate is the norm. But we would be wrong to assume that this period of stability will continue: not only are the human impacts on greenhouse gas concentrations forcing the climate to change, but the previous 90,000 years show that instability, not stability, is the more usual pattern.

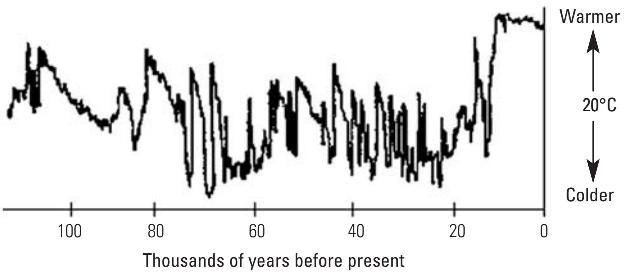

Fig. 1
Temperature change over the past 100,000 years as interpreted from a Greenland ice core oxygen isotope proxy (20)

Current levels of greenhouse gas concentrations have led to an increase in average global temperature of 0.75°C since the mid-twentieth century, and because of the lag between an increase in concentrations and the trapping of heat, the planet is due for an equal amount of temperature increase by 2100, even if greenhouse gas emissions were to cease immediately (22).

This has led to changes in the physical environment: later freezing of lakes and earlier break-up of ice in the spring (21), retreat of glaciers in Alaska, Greenland and elsewhere. In the tropics, the glaciers on top of high peaks such as Kilimanjaro are due to vanish within 15 years (35).

Arctic sea ice is retreating at unprecedented rates (12, 15). That retreat is accelerating as would be predicted from the heat absorption capacity of open water as compared to ice, so an ice-free Arctic is predicted for 2030 if not earlier (15, 38). Sea levels are also rising, primarily because of the thermal expansion of seawater (15).

In addition, there is a statistically significant increase in wildfires in the American West (36). Longer and warmer summers and earlier snow-melt lead to dryer environments and higher fire vulnerability. It is also possible that there will be an increase in the number of fiercely intense tropical cyclones in the future, although there still is some scientific debate on the question.

A changing environment: the effect on species and ecosystems

All these physical changes obviously affect species and ecosystems. In contrast to a decade or two back, there are signs of climate-driven change in nature all over the globe. In many places where there are good records, earlier flowering times for certain species, such as those in Central England, have been documented (9). There have also been changes in the timing of events in the seasonal cycles of certain animal species (phenology), e.g. birds such as Tree Swallows (*Tachycineta bicolor*) are nesting earlier and laying their eggs earlier (8).

The geographical occurrence of some species is also changing. In North America, Edith's checkerspot butterfly (*Euphydryas edithae*) has already shifted upward in altitude and northward in latitude (26) (Fig. 2). Similarly, the sooty copper (*Lycaena tityrus*) in Europe moved north to Estonia in 1998 and was recorded as breeding the following year (25). These kinds of changes might have seemed anecdotal previously, but have now been demonstrated to be statistically robust (27, 32). In an interesting echo of change in species location, in the United States of America, the National Arbor Day Foundation found it necessary to publish a new map of Hardiness Zones, which guides gardeners as to which plants can and cannot be grown with reasonable success where the gardeners live (2).

The changes are not just in terrestrial ecosystems but in aquatic ones as well. In marine environments, plankton species have been shifting geographically and so have fish species. In America's great estuary the Chesapeake Bay, the southern boundary of the eel grass (*Zostera marina*) community, an important element in the ecology and productivity of the bay, has been moving steadily northward. Eel grass has a distinct upper temperature limit and as the bay has warmed the area in which it grows has decreased by 25% as a consequence (31).

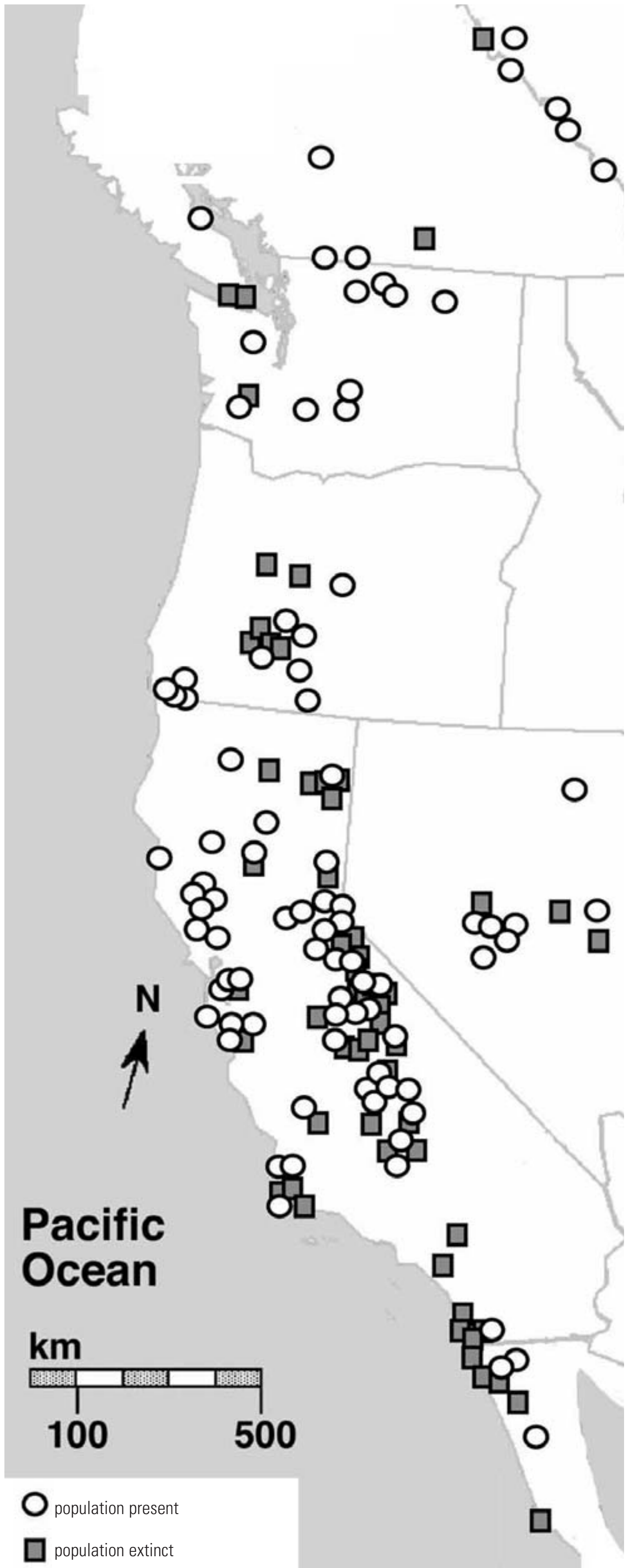

Fig. 2
Range shift of Edith's checkerspot butterfly *(Euphydryas editha)* moving northward and up in altitude (24)

Tropical ecosystems are affected as well. Costa Rica's legendary Monteverde cloud forest is experiencing more frequent dry days as climate change raises the altitude at which clouds (virtually the sole source of moisture for cloud forests) form (31). It is believed that the golden toad (*Bufo periglenes*), which has not been seen in Monteverde for about 20 years, is the first species to be driven to extinction by climate change (30, 31). Other changes occurring in Monteverde include the movement upslope of a nest predator (toucan) of the iconic bird of the Aztecs, the Quetzal (*Pharomachrus mocinno*) (31).

Tropical coral reefs – in many senses the marine equivalent of tropical rain forests – are also being affected. Forty years ago coral bleaching events – in which the partnership between the coral animal and an alga breaks down and the alga is expelled – were virtually unknown. Today they are widespread, occurring in many locations annually.

In the Arctic there is considerable and rapid change, as ice melts and glaciers retreat. In 2007 there was a dramatic decrease in the extent of the Arctic ice toward summer's end (17). This has major impacts on the many species related to ice. The polar bear (*Ursus maritimus*) of course has attracted a great deal of attention, but many others are being affected. For example, many bird species depend on the Arctic cod (*Arctogadus glacialis*), a fish species that eschews open water and swims just under the ice. Seabird species nesting on land must fly to the edge of the ice to get food for their chicks. At a certain point the distance is too great and their nests fail.

So, nature is on the move in response to climate change. These are, nonetheless, relatively minor ripples of change in the biological fabric of the planet. The real question is what may lie ahead.

Future consequences of a changing environment

The lag between increases in greenhouse gas concentrations and the consequent accumulation of heat means that over the next 100 years the planet is in store for an equal amount of warming to that which has already taken place since the mid-twentieth century (0.75°C). The first paper to look at what double pre-industrial levels of greenhouse gas might mean for the biota (34) estimated a consequent extinction of 20% to 30% of all species. Interestingly, the 2007 report of the Intergovernmental Panel on Climate Change (IPCC) predicts extinction on a similar scale (15).

Temperature increases, which will be greater toward the poles (particularly in the northern hemisphere because there is more land), are not the only shift that will take place; changes will also occur in levels of precipitation and other forms of moisture. Temperature and moisture are the two most important environmental parameters for terrestrial organisms, while temperature and pH are the two most important for aquatic species.

The prairie pothole ecosystem in the American mid-west is one of the world's most important wetland regions and provides critical habitat for 50% of North American migratory waterfowl. Already more than half-drained for agricultural and other use, the remaining potholes (shallow ponds) from the upper mid-west to Alberta, Canada, are already experiencing warmer and drier summers (16). Moreover, analysis by global computer models of the requirements of the sugar maple (*Acer saccharum*) – the flagship species of the spectacular autumn color of New England – shows that with double pre-industrial CO_2 levels New England would be bereft of its signature tree species (10, 11).

It is clear that cold water fish species such as trout will no longer be able to survive in the southern part of their range as it warms (1). There will also be complex interactions. In the Hawaiian islands, the surviving species of the great Hawaiian Honeycreeper evolutionary radiation survive only above a certain altitude – the 'mosquito line' – above which the introduced mosquito that transmits an introduced bird malaria (fatal to honeycreepers) does not survive. That line will move upslope in a warming world so the mosquito- and malaria-free zone will shrink (19) (Fig. 3). A somewhat similar interaction has already been observed between warming, an introduced species (the emerald ash borer [*Agrilus planipennis*]), and the American ash (*Fraxinus americana*), an important commercial tree species in the United States (7).

Species in certain kinds of locations will be particularly vulnerable. Those on high mountains, such as the American pika (*Ochotona princeps*), which exists in isolated populations on a number of peaks in the American West, will eventually have no further upward to go in altitude (3). Some coastal species will be vulnerable to rising sea level. Species on low-lying islands, such as the Key deer (*Odocoileus virginianus clavium*) in Florida, will eventually have no land left.

The outlook for tropical coral reefs is particularly bleak. With increasing temperature, bleaching events will become annual, and eventually they will occur so frequently that the coral will be unable to recover (14). Once the reefs are no longer living, a lot of the rest of the species that make up coral reefs will no longer be able to survive. Obviously, that will have a major impact on the coastal communities that depend on them for sustenance.

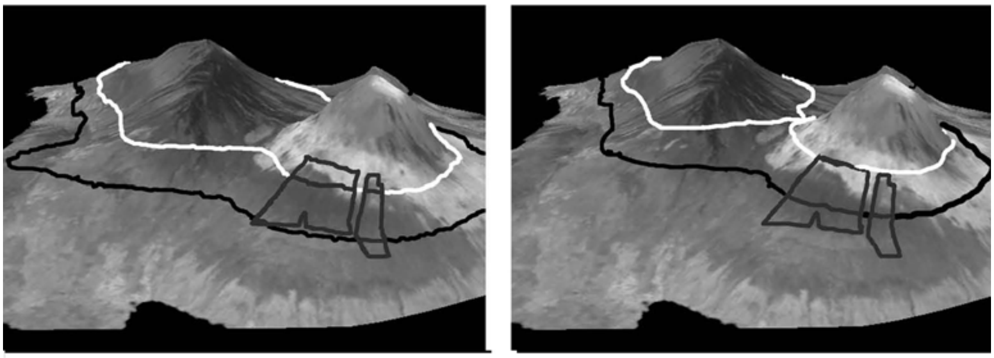

Fig. 3
Present and projected future positions of 13°C and 17°C isotherms in the Hakalau Forest National Wildlife Refuge, Hawaii
At temperatures greater than 17°C avian malaria thrives; at less than 13°C there is no transmission (20)

In some places where the biology is well known, it is possible to make projections species by species. This has been done for plants in the Cape Floral Kingdom in South Africa (23) and for the vertebrate species of Australia's Queensland rain forests (37).

Difficulties in predicting the future impact of climate change

There are important factors which make it complicated to predict how the natural world is likely to respond to further climate change. One involves the human modification of landscapes (28, 29).

Climate change of course is nothing new in the history of life on earth. Glaciers came and went with no apparent major impact on biological diversity. Today, however, the major conversion of landscapes to human uses seriously curtails the opportunities for species to track their required conditions. Basically, landscape modification has created an obstacle course for the normal species response to a changing climate.

A second major complication is that biological communities do not move as communities; rather, the individual species move each in their own direction and at their own rate. This can be seen in the response of species movements after the retreat of the glaciers (13) (Fig. 4). We can, therefore, anticipate that ecosystems as we know them will disassemble and the individual species will assemble into novel ecosystems.

A third major difficulty is that change will not be linear or gradual. This is certainly true of climate change itself, as climate history clearly shows. It is also true of biological change. Threshold change (sudden, fundamental change) is already being observed in ecosystems. In the coniferous forests of British Columbia, southern Alaska and parts of the northwest United States, for example, longer and warmer summers enable the native pine bark beetle (*Dendroctonus ponderosae*) to have one more generation per year (4). That is just enough to tip the balance in favor of the beetle, with massive tree mortality as a consequence.

The final complication is the frightening one of system change. The hydrological cycle of the Amazon basin literally makes half the basin's rainfall, but in turn is dependent on moisture moving westward in air coming from the South Atlantic (33). In 2005 that system broke down as Atlantic circulation, perhaps in a preview of climate change, generated a severe drought with an impact deep into the central Amazon (6). The Hadley Center's Global Circulation Model shows such an effect could occur in the future, leading to concern about possible Amazon dieback (15), a prospect sufficiently serious that it is being studied by the World Bank.

In the oceans the elevated concentrations of CO_2 in the atmosphere have led to an increase in acidity of approximately 30% (0.1 pH unit) (18). This is a profound change in oceanic chemistry, with worrisome implications for all species that construct shells and skeletons out of calcium carbonate, including those that exist in untold numbers at the base of marine food chains. Those organisms depend on the calcium carbonate equilibrium that is in turn dependent on pH and temperature – if the water is colder and more acidic it will be harder to mobilise calcium carbonate.

Other possible system changes include the first signs of positive feedbacks in the climate system as warming releases gases hitherto locked up in a frozen state ('positive feedbacks' are events triggered by change which then cause further change in the same direction, as opposed to 'negative feedbacks' which cause change in the opposite direction). As the tundra warms and permafrost is lost there is potential for major release of methane, a very potent greenhouse gas (22).

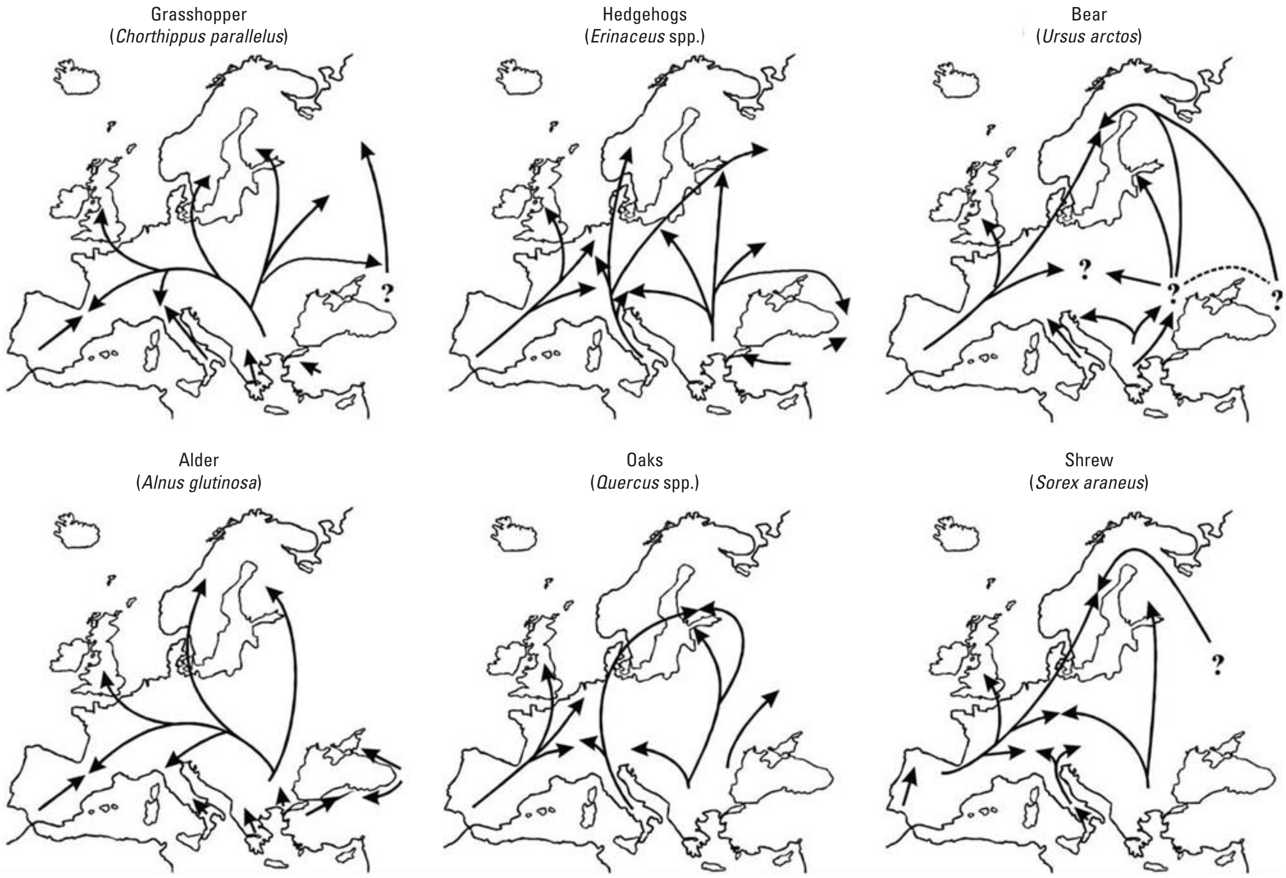

Fig. 4
Post-glacial colonisation patterns for species from southern Europe (20)

Conclusion

Beyond the spectre of climate change there will also be changes that come from various efforts to limit the amount of greenhouse gases and climate change. These obviously can have epidemiological consequences in themselves. Since about 20% of current annual greenhouse gas increase comes from deforestation, a major effort to reduce deforestation and to reforest can change the ecological landscape for diseases and vectors. The increase of agriculturally derived biofuels will also have a major impact on landscape ecology and the etiology of particular diseases.

The implication of climate change and some of the efforts to address our energy base and management of the carbon in ecosystems, is that a great deal of change lies ahead: change that clearly represents an unfolding ecological picture with great implications for epidemiology.

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Le changement climatique et la biodiversité

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Résumé
Les phénomènes périodiques naturels des plantes et des animaux (phénologie) et les distributions des espèces sont déjà affectés par des changements importants. Des franchissements de seuils entre écosystèmes (changements brusques et fondamentaux) commencent à être observés dans la nature. On peut s'attendre à un réchauffement de la planète au moins équivalent à celui constaté jusqu'à aujourd'hui. Ces données suggèrent que la nature et les écosystèmes connaîtront de grandes fluctuations dont les conséquences épidémiologiques risquent d'être considérables.

Mots-clés
Acidification de l'océan – Changement climatique – Changement d'affectation des terres – Changement systémique – Écosystème – Franchissement de seuil.

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Cambio climático y diversidad biológica

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Resumen
Además de cambios generalizados en los calendarios naturales (fenología) de plantas y animales, ya se han observado alteraciones en la distribución de ciertas especies. Los ecosistemas empiezan a sufrir transformaciones cualitativas (cambios repentinos y fundamentales) ligadas a la superación de determinado valor umbral. El calentamiento que va a experimentar el mundo natural será de magnitud igual o mayor que el que ya se ha producido. Todo ello augura un futuro de condiciones muy cambiantes en la naturaleza y los ecosistemas, lo que tendrá profundos efectos en el terreno de la epidemiología.

Palabras clave
Acidificación de los océanos – Cambio climático – Cambio dependiente de un valor umbral – Cambio sistémico – Cambio en los usos del suelo – Ecosistema.

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