Responses of Species to Changes in Climate Determine Climate Protection Targets

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Abstract

Widespread ecological impacts of climate change are visible everywhere. Plants and animals respond rapidly to the ongoing changes. Responses significantly differ from species to species and from year to year. Traditional impact assessments focused on long-term range shifts of biomes. Studies focusing on species-specific responses depict more impacts. Over the last decade, many more ecological responses have appeared than expected from an average warming trend alone. Impacts and vulnerability are therefore likely to be underestimated. Ecosystems respond faster to changes in extreme weather than to average climate. This explains the more rapid appearance of ecological responses throughout the world.

Tighter political climate protection targets are therefore urgently needed. Based on current understanding of the response of species and ecosystems, we propose that efforts be made to limit the warming to maximally 1.5^{o}C above pre-industrial levels and limit the rate of change to less than 0.05^{o}C per decade.

Introduction

The history of the Earth's climate has been characterized by many changes. But the extent and the rate of current climate change exceeds most natural variation. Most of this warming is attributable to human activities, in particular to the increase in the atmospheric concentrations of greenhouse gases from energy generation, cement production and deforestation. IPCC [1] stated that 'an increasing body of observations gives a collective picture of a warming world and other changes in the climate system.' Climate change already has produced considerable impacts on species and ecosystems, human health and society [2, 3]. These impacts are now also being documented more carefully [e.g. 4, 5].

Impacts represent complex phenomena that generally have multiple causal agents. Thus, while many are consistent with warming trends, it is impossible to state for any single weather event that it is due to anthropogenic warming. A statistically rigorous attribution to global warming is often impossible because long-term data on weather and climate are rarely collected simultaneously with impacts. An observation of specific responses seems anecdotic but all responses put together start to corroborate clearer proof. The analysis and mapping of such few studies by IPCC [i.e. IPCC's global map of observed responses by 6] led to the conclusion that 'recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems'.

As a response to these climate change impacts, the United Nations Framework Convention on Climate Change (UN-FCCC) was established in 1992. Its objective is to realize stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved, among others, within a time frame sufficient to allow ecosystems to adapt naturally to climate change. A basic question is which period ecosystems require to adapt naturally. Climate protection targets have been proposed but these were never seriously discussed within the UN-FCCC. Only Europe stated that climate change should be limited to 2 ^{o}C. IPCC clearly demonstrated that a global mean increase in average surface temperature of more than 1 - 2 ^{o}C leads to rapidly increasing risks for adverse impacts on ecosystems [the 'Reasons for concern' or 'Burning Embers' diagram in 6]. In its own assessment, the UN Convention on Biological Diversity (UN-CBD) reviewed IPCC's evidence [7]. They also concluded that a climate change beyond 2^{o}C was unacceptable for ecosystems and biodiversity.

In this paper we review recent literature on observed ecological responses of climate change. The review updates the last IPCC assessment. Then we compare the expected changes derived from impacts models and scenarios with the observed responses. One of the problems here is that most impacts assessments apply large climate changes (more than 2^{o}C warming), while the observed responses result from a less than a 1^{o}C warming. Another problem is that impacts assessment aggregate ecosystems into coarse units, while the observed responses show that each species display unique responses. We aim to bridge these shortcomings and analyze why observed ecological responses are nowadays reported more frequently.

Observed Changes

Briffa et al. [8] have reconstructed temperature by comparing northern Hemisphere tree-rings over the last 1,000 years. They found that the magnitude of 20th century warming is the largest and exceeds by far all natural climate variations during this period. These changes are unusual in terms of both magnitude and rate of temperature change. In addition, direct measurements show that the 1990s are the warmest decade of the century. This rapid warming has continued during the first years of the 21st century.

The increase in global temperatures has resulted mainly from a significant reduction in the frequency of much below normal seasonal mean temperatures across much of the globe, with a corresponding smaller increase in the frequency of much above normal temperatures. Klein Tank [9] recently analyzed European patterns of climate change and came to a surprising conclusion: 'Although there have been obvious changes in the mean climate, most of the observed ongoing climate change can be attributed to changes in the extremes'. His analysis showed statistically significant and non trivial changes in extremes: fewer cold extremes, more heat waves, smaller diurnal and seasonal ranges, more precipitation that come mostly in intense showers. He further concludes that larger extremes should be expected in the future, often aggravated by systematic interactions. This was illustrated by the exceptionally hot summer in Europe in 2003. The high temperatures were partly caused though a lack of soil moisture and evaporation, which raised temperatures more rapidly than ever anticipated.

The first signs that this warming causes obvious changes in ecosystems come from the high latitudes and alpine systems. Anisimov [10], for example, analyzed long-term data for Russia and Siberia and concluded that permafrost was thawing. Such melting actually began in the middle of the nineteenth century and warming has accelerated more over the last decades in all polar regions than in any other region of the world. The recent Arctic Climate Impact Assessment [11] provided well-documented evidence of these large changes in observed ice thickness and ice cover and the subsequent negative impacts on polar ecosystems. Similar trends are reported from Antarctica.

Glaciers are also retreating almost everywhere in the world. Especially in the tropics, this process proceeds rapidly. The last ice of the glacier on mount Kilimanjaro, for example, will likely melt before 2020. This threatens unique alpine ecosystems, local biodiversity and runoff volumes. Similar trends are observed for most of the Himalayan glaciers. The accelerated melting of glaciers, permafrost, ice and snow cover will alter the hydrology of many rivers in this region. Water availability downstream could be threatened and adversely impact ecosystems, biodiversity and the livelihoods of many people.

Climatic change has also increased the length and intensity of summer drought in many regions. This has increased the susceptibility of ecosystems to fires. Over the last decade fires frequencies increased in many regions. For example, fires burned up to 810,000 hectares of rainforest land in Indonesia, including almost 100,000 hectares of primary forest and parts of the already severely reduced habitat of the Kalimantan Orang Utan.

Since the seventies, satellites are used to monitor changes in the environment. Myneni et al. [12] analyzed such data to detect a warming over land in the Northern hemisphere. From their data for 1981 to 1991 they found surprisingly large changes over many regions. They detected an earlier greening of vegetation in spring of up to 10 days and a later decline of a few days in autumn. These changes indicate a longer growing season to which vegetation immediately responds. Such phenomena have also been observed elsewhere. Several studies, for example, report a polewards or upwards shift of the treeline border between trees and tundra and increases in the width of tree rings.

One of the most obvious indicators of ecological impacts is phenological change. Phenology deals with the times of annual recurring natural events like flowering, leaf unfolding, fruit ripening, leaf coloring and fall, migration, and spawning, and can be observed with easy means everywhere. Many phenological networks that monitor the timing of life cycle events have been established. The records go back hundreds of years and most still expand. This now helps us to assess long-term changes. In The Netherlands, for example, systematic phenological observations have been made from 1869 till 1968. In 2001 this Dutch network was successfully revived under the name Nature's Calendar (http://www.natuurkalender.nl). Since then, thousands of volunteer observers have submitted their own phenological observations on plants, birds and insects. Many species groups have showed significant changes in the timing of their own life cycle events (c.f. Figure 1), which are documented in the recently published book "Opgewarmd Nederland" [5].

Other studies highlight the intricate linkages between species. The long-term observations made on the Pied flycatcher [13], for example, revealed that although the Pied flycatcher advanced its egg laying date by 7 days, the main food source for their young, caterpillars of the Winter moth, appear 14 days earlier than they did in the past. There now develops a timing mismatch, which rapidly reduces breed success of the Pied flycatcher. With the enormous complexity of the whole food webs in natural systems, it is highly likely that many more problems will occur, although our lack of knowledge precludes quantifying the potential size of the problem.

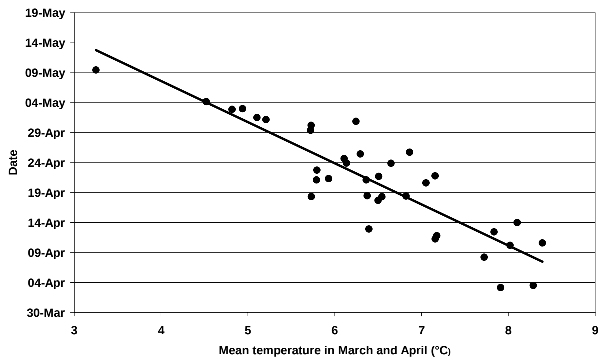

Figure 1. Relation between timing of Dutch Birch flowering and spring temperature.

The distributions of plants and animals are well-defined. They are adapted to environmental conditions within their habitat, defined by many interacting factors. With climate change, several factors will change. In order to survive, species have two options: adapt to the changes so they can continue to reproduce within a given area or move to another area where conditions are better. The question, however, is whether species are able to migrate to other areas. A tree, for example, will not be able to move to another area and can only depend on the successful distribution of its seeds to other areas that are more suitable.

The climate change indicator report of the EEA [14] concludes that over the past decades a northward extension of many plant species has been observed in Europe. In Western Europe, warmth demanding plant species have become more abundant compared with 30 years ago. Despite the increase in abundance of warmth demanding plants, a remarkably small decline in the presence of traditionally cold-tolerant species is observed. Endemic species have been replaced by more general species in many mountain regions due to a number of factors, including climate change. Higher temperatures and longer growing seasons appear to have created suitable conditions for plant species that have migrated upward and which now compete with endemic species. It is expected that species with a high migration capacity have the ability to quickly change their geographic distribution. Recent changes in the Dutch lichen flora provide such example. Since the end of the 1980's Mediterranean and tropical species have been increasing. Species with a boreo-montane distribution are decreasing.

Increasing evidence indicates also whole food webs in marine systems are undergoing major changes [14]. Some zooplankton species have shown a northward shift of up to 1000 km. These shifts have taken place southwest of the British Isles since the early 1980s and, from the mid 1980s, in the North Sea. The diversity of colder temperate, sub-Arctic and Arctic species has decreased. Furthermore, a northward extension of the ranges of many warm-water fish species in the same region has occurred. Most of the warm-temperate and temperate species have migrated northward by about 250 km per decade, which is much faster than the migration rates expected in terrestrial ecosystems.

Also insects have the ability to quickly respond to climate change. This is illustrated by the rapid recent northward expansion of the Mountain pine beetle in Canada. Data from the Canadian Forestry Center show a large increase in the number of infestations occurring in areas that were historically climatically unsuitable. The mountain pine beetle population has doubled annually in the last several years. It caused mortality of pine trees across two million hectares of forest in British Colombia in 2002 alone. These large scale pest infestations have large economic impacts. Another range change that is becoming a societal problem is the northward expansion of the Oak processionary caterpillar in the Netherlands. After the first observations in 1991 in the southern part of The Netherlands, it advanced its distribution range to the mid-Netherlands. This southern European species requires warm conditions. The caterpillars are a concern to human health because of the many stinging hairs that can cause rashes in skin and bronchial tubes.

All above examples (and there are many more) show that recent changes in climate have caused significant ecological changes everywhere in the world. Such vast response is not expected while assuming just gradual climate change. The changes observed should be seen in the context of a global mean average increase in temperature of less than 0.5 °C.

Are these responses consistent with expected changes?

Impacts of climate change are now observed everywhere and many unexpected changes occurr. The question that arises is "**Were these changes expected to happen so fast and with such a magnitude?**" To address this question we have to evaluate how future impacts of climate change are determined.

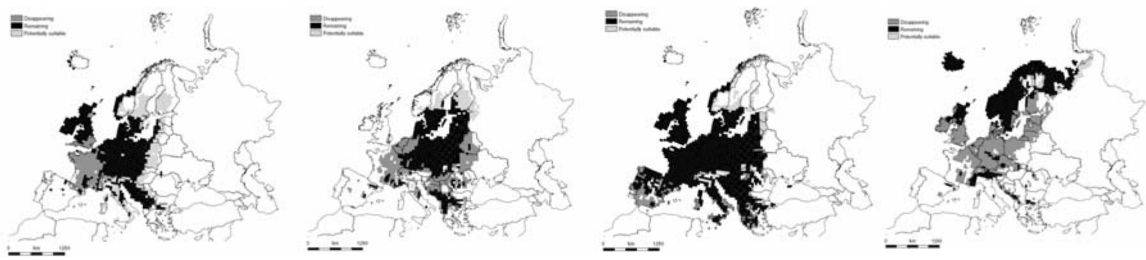

Figure 3. The projected changes in different European plant species ranges [after 17]

Most traditional impacts assessments have used two components: scenarios for a gradually changing average climate and models that simulate possible responses. Applying this approach is straight forward and potential impacts of different systems are established. These results generally indicated that climate change was an immediate threat. Only boreal forests and tundras were considered vulnerable. Most of these impact assessments are done for doubled-CO_2 conditions or larger levels of warming. The rate of change was further ignored. Only the magnitude was considered. Emanuel et al. [15], for example, were the first to use this approach. They showed that a doubled-CO_2 climate change would shift the distribution of 35% off all ecosystems. Their pioneering result can still be compared favourably with recent studies with advanced models. Of course, these studies have added more spatial detail, used dynamic models, more realistic species and ecosystem responses but the magnitude of impacts has not changed much.

Now such transient climate scenarios are commonly used. These studies generally show little response during the first few decades, then an accelerated response, followed by a levelling off after a century. Still, the simulated impacts replicate those of the equilibrium approaches. Leemans and Eickhout [16] used such a simple transient scenario approach to calculate whether vegetation can adapt to the simulated changes over a century. Grasses, for example, disperse quickly, while tree populations disperse much more slowly. At a warming of 1 ^{o}C in 2100, only 50% of the affected ecosystems were able to adapt. With increasing rates of warming, the adaptation capacity rapidly declines. Their study indicated that with a warming of 0.1 ^{o}C per decade, most ecosystems would not adapt naturally.

One of the problems with these approaches, however, is their coarse aggregation of the unit of analysis. Generally, less than 30 biomes are distinguished. Changes start at biome margins and rarely affect whole biomes. Using such aggregated models conceals many relevant impacts at the local scale. Few studies have used species models instead of biome models [17, 18]. This supports the assumption that biomes do not respond as unique entities but species population probably do (Figure 2). All these studies show many more subtle impacts in many more regions than just along margins of biomes. In fact, Thomas et al. [18] indicated much larger adverse impacts using species than Leemans and Eickhout [16] did using biomes. This means that most traditional impact assessment underestimate projected future impact levels. Impacts are thus likely more rapid, diverse and widespread than those depicted in traditional impact assessment.

Most of the changes that we observed over the last decade are consistent with a warming climate. However, many of the changes that we are experiencing occur much faster than indicated with the traditional climate scenario–model impact studies. For example, Leemans and Eickhout [16] simulate that only 5% of all land-based biomes are affected with a 0.5 ^{o}C simulated increase in temperature compared to pre-industrial temperatures. The impact levels of Thomas et al. [18] are a few percentages higher. Such an increase in temperature occurred, nonetheless, over the last few decades and modelling by these authors could therefore be a realistic validation exercise to compare to observed changes. The observed changes indicated that all species, not just a small percentage, respond immediately, especially when phenology is considered. Additionally, many species have already start to shifted their ranges. Our overall impression is that the observed responses are more widespread and appear more swiftly than models suggest.

When we analyzed the observed responses of the biota, most result from extreme climatic events. Generally responses to extreme changes are much more apparent. For example, the early budding and leafing in The Netherlands in 2004 was clearly caused by unexpectedly high temperatures in early February. Also the emergence of subtropical lichen species is clearly encouraged by more frequent hot and dry summers and mild winters. Klein Tank's conclusion [9] that extreme weather events contribute most to recently observed climate change, explains why ecological impacts are becoming so abundant over the last decade. Ecosystems respond most rapidly and vigorously especially to these large events.

Many have argued that the observed changes show that species and ecosystems are resilient and can thus easily cope with these climate changes. Unfortunately, it is not as simple as it seems. The continued warming trend pushes many species into conditions that they have never experienced. This increases stress. Many assessments, however, show that many such stressed and degraded systemsare rapidly replaced by better adapted ones. That may be true, but degradation generally goes fast (days to decades), while recovery is slow (decades to millennia) and often constrained by habitat fragmentation, pollution and other stressors. This will lead to local die-backs and increase local extinction rates. Additionally, opportunistic species with wide ranges and a rapid dispersal will become more abundant, while specialist with narrow habitat requirements and long lifetimes will decline. Unfortunately, extreme events are neglected in the traditional impact assessments. This is an obvious reason for the apparent underestimation of current ecological impacts. The actual unfolding of climate change now will provide most likely many more surprises. Species, communities, landscapes, ecosystems and biomes are much more vulnerable than is commonly appreciated. With continued climate change over the coming decades, natural responses of species and ecosystems (c.f. Article 2) will not be adequate for survival, and many ecosystems will rapidly become depauperated.

Conclusion: many more reasons for concern

IPCC [1] indicated that above 2^{o}C warming risks rapidly increase. Although they explicitly mentioned that below that level, there already will be risks, they judged (at that time) that these risks would be acceptable. By linking the observed changes in species and ecosystems with the changes in extreme weather events, we provide a more consistent correlation of forcing and response. With such insights it seems obvious that traditional impact assessment approaches are inadequate for precisely estimating the extent and magnitude of responses. They only provide the proper direction.

We conclude that a target of 2^{o}C is too high. Even with small changes, there will be unproportionally large changes in the frequency and magnitude of extreme events and consequently, the unpredictable, but devastating impacts to species and ecosystems, even with a moderate climate change (an increase of 1 to 2 ^{o}C). Defining tight climate protection targets and subsequent emission reduction targets is becoming, more than ever, a must. **Based on our current understanding of responses of species and ecosystems, we propose that efforts be made to limit the increase in global mean surface temperature to maximally 1,5^{o}C above pre-industrial levels and limit the rate of change to less than 0.05^{o}C per decade.**

The maximum of 1,5 ^{o}C tightens the existing climate protection targets of 2^{o}C considerably. This is necessary, however, because impacts are more widespread, threaten delicate species interactions, and are triggered by the more rapidly occurring changes in extreme events. This effectively combined IPCC's burning embers 'Unique and threatened systems" and "Extreme climate events' and this causes additional reason for concern. Together, this creates a strong argument for simultaneously limiting the rate of change to maximally 0.05 ^{o}C per decade.

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