Climate change and mass extinction: What can we learn from 200 million year old plants?

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Abstract

We are facing unprecedented times in terms of the speed of ongoing climate change. Palaeobotany, the study of fossil plants offers the potential to investigate how levels of carbon dioxide in the Earth's atmosphere – an important greenhouse gas – has changed over the last 400 million years of Earth history. Using a simple inverse relationship between the number of stomata (microscopic breathing pores) on the leaf surface and the concentration of carbon dioxide in the atmosphere we can reconstruct how carbon dioxide levels have waxed and waned over time. A long-term view of atmospheric evolution enables us to place the recent > 25% rise in carbon dioxide into a longer term perspective. Our research at UCD explores critical questions such as; what role have greenhouse gasses played in global warming events in the geological past? More simply put we can address whether increases in greenhouse gasses in the past resulted in global warming. We are also actively studying whether global warming was wholly, or in part, responsible for any of the five great 'mass extinction events' that punctuated the history of life on Earth. In this paper I will review the long term record of atmospheric carbon dioxide from computer modelling and fossil plant evidence and briefly illustrate the effect of past global warming events on natural ecosystems using a database of over 4000 fossil plant specimens collected from Triassic and Jurassic (205 to 195 million years) aged rocks in East Greenland. I will review fossil plant studies which show that natural global warming events in the past have adversely influenced the ecology and diversity of forest ecosystems and conclude by highlighting the possible implications of this research for the future of Irish ecosystems.

1 Introduction

Over the past 200 years of western industrialization the concentration of the greenhouse gas, carbon dioxide, has increased from a pre-industrial level of ~280 parts per million (ppmV) to 386 ppmV [1]. Fossil fuel use and land use change – from natural forest to agricultural – are the two primary reasons for this startling trend. If we continue using fossil fuels at the current rate it is anticipated that current CO_2 concentrations will double by the end of this century [2]. The question is; should we be concerned? Carbon dioxide is not a pollutant gas, it is a natural component of our atmosphere, however, it *is* a greenhouse gas and because of its heat trapping properties global climate models predict that a doubling of CO_2 will result in a global temperature rise of between 1.5 and 4°C by the year 2100 [2]. Measurements of the CO_2 content of air bubbles trapped inside Antarctic ice cores have revealed that CO_2 concentrations have waxed and waned through the last 2 million years of ice age cycles. During cold (glacial) climate phases, CO_2 concentrations as low as ~172 ppmV prevailed whilst during the warm phases (interglacial) the CO_2 levels rose to a maximum of 300 ppmV [3].

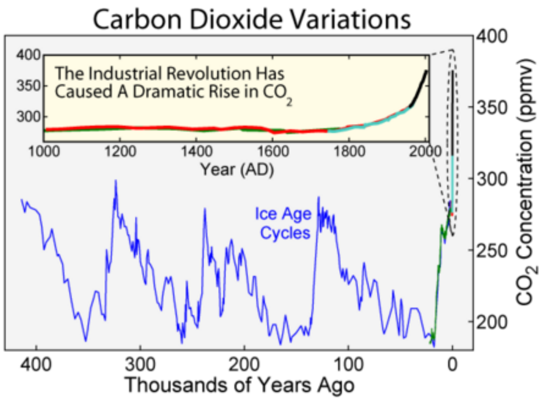

Figure 1 – Trends in atmospheric CO_2 concentration from ice core measurements over the last 400,000 years (blue and red) compared with a more detailed record from direct measurements over the last 50 years (black). Image created by Robert A. Rohde. See http://www.globalwarmingart.com/wiki/Image:Carbon_Dioxide_400kyr_Rev_png for data sources.

Thus, ice core records illustrate that the current CO_2 concentration is unprecedented – at no time in the last 2 million years of Earth history has the level of CO_2 in the atmosphere or its rate of increase been as high as it is today. This is indeed a sobering comparison however if we are heading for a so-called 'greenhouse world' when CO_2 concentrations will rise even further, the ice ages do not serve as the best analogue to understand and project future consequences for the biosphere and our climate system. We need to look further back into 'deep time' when carbon dioxide levels were as high, and even higher, than they are today. The use of 'CO_2-proxies' is the only mechanism of indirectly estimating how atmospheric CO_2 has fluctuated beyond the direct 800,000 year record provided by analysis of ancient air within ice cores. A CO_2 proxy is any biological, chemical or physical indicator of atmospheric CO_2 concentration.

2 Fossil stomata as indicators of past CO_2

In 1987 a Cambridge botanist, Professor Ian Woodward observed that the density of stomata on leaf surfaces was inversely correlated with the concentration of atmospheric carbon dioxide. He made this observation on dried plant material (herbarium sheets) of native English trees collected over the last hundred years; a time when CO_2 concentrations increased by over 30%. This simple observation has become a very powerful tool in paleontological research as it has enabled us to estimate the CO_2 concentration of past atmospheres by simply counting the frequency of stomata on fossil leaf surfaces. Put more simply, it offers the opportunity to track how atmospheric carbon dioxide content has changed over the last 400 million years of Earth history!

3 A long-term view of atmospheric CO_2

The results from studies of changes in fossil plant stomatal frequency for different geological

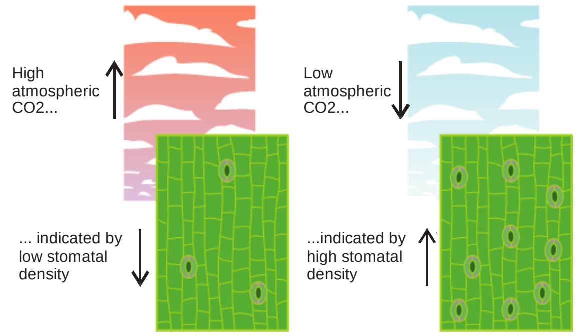

Figure 2 – A graphic illustrating how the stomatal proxy method is used to estimate the carbon dioxide concentration of past atmospheres.

intervals have been combined with other proxy CO_2 sources to build a long-term picture of how atmospheric carbon dioxide levels have changed over geological time (see Figure 3). This long-term CO_2 record reveals that there have been times in Earth history when CO_2 concentration was much higher than today, such as during the

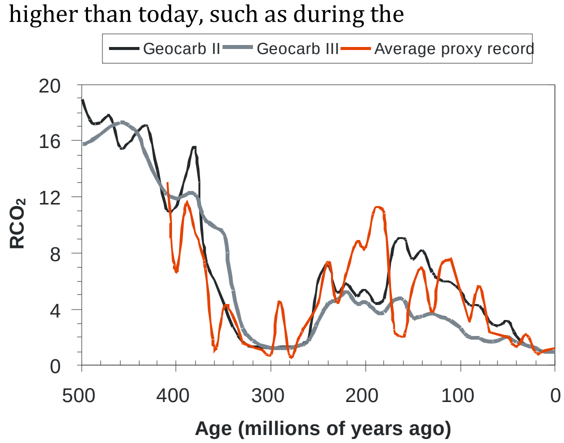

Figure 3 – .Changes in atmospheric carbon dioxide concentration over the last 500 million years based on model estimates (black and grey lines) by Robert Berner, Yale compared with proxy estimates (in red) complied by Dana Royer. RCO_2 is a ratio scale of past to present CO_2 concentration. Figure redrawn from [4].

Mesozoic (~200 to 65 million years ago), the so called age of dinosaurs. There have also been periods of time when atmospheric CO_2 concentrations were significantly lower or equivalent to present levels (such as during the Carboniferous period ~354 to 200 million years ago). The most striking feature of these records is that CO_2 levels and global temperatures have been closely coupled over the last 450 million years, with low CO_2 episodes associated with the formation of extensive polar ice sheets [4]. Conversely, during times of high atmospheric CO_2, the polar latitudes are ice free. These long-term records of atmospheric composition and climate to place more recent historical trends into context (see Figure 3). Such an exercise reveals some extremely sobering facts; we learn that the rate of CO_2 rise of our last century –driven by fossil fuel burning and land use change is fifty times faster than that associated with any of the best studied natural global warming events in the geological past. These records also demonstrate that the current CO_2 concentration is higher than anytime in human evolutionary history and that by the year 2100 CO_2 levels in the atmosphere will reach levels not seen since the Eocene, some 50 million years ago. Fossil plant evidence from all over the world provides strong evidence that the Eocene was also a time of high global warmth. Mangrove swamps fringed the south coast of Britain. Forests of Dawn Redwoods extended well inside the arctic circle, an place today that is completely treeless due to the harsh climatic conditions, and forests of Southern Beech were extensive across a completely ice free Antarctica.

3 Global warming and mass extinction

Our research group at UCD uses the past as a guide for the future. Specifically, we study natural global warming events in the past which were driven by increased levels of greenhouse gasses in the atmosphere, to understand the potential future biological consequences of CO_2-induced global warming. One such event was the so called Triassic-Jurassic boundary over 200 million years ago. Over 4000 fossil plant specimens from Triassic and Jurassic aged sediments in East Greenland were collected in 2002 from before, during and after a natural global warming event in order to document the effects on the biodiversity and ecological structure/composition of ancient forest ecosystems. This study has revealed [5, 6]:

1. Catastrophic loss of plant diversity in response to climate change,
2. Complete replacement of ecological dominants in response to climate change
3. 80% extinction of East Greenland species in response to climate change
4. Certain characteristics increase a species extinction risk including ecological rarity, reproductive specialization and large leaf size.

Figure 4 – .A photo of the treeless tundra vegetation in East Greenland today compared with an artistic reconstruction of what the vegetation looked like 205 million years ago (Late Triassic) in the exact same location when global temperatures were 3°C higher than today. Our research has shown that a global warming of 6°C results in a complete collapse of the Late Triassic ecosystem shown above.

We have also hypothesized that the changes in the structure and composition of the ancient forests in East Greenland had a knock-on effect on animals and contributed to the 22% extinction of animal families observed at this time [3].

4 Implications for future Irish ecosystems

Our research typically focuses on times in the deep geological past when the species make-up of vegetation was very different from that of today. Indeed many of the fossil species we study are extinct. We cannot therefore make specific prediction on the future fate of most species in the Irish vegetation. The power of our method comes from the fact that we can observe general ecological responses to past global warming events and we can identify certain biological traits which either increase a species risk of extinction or improve a species chance of survival into the future. One of our most interesting findings from fossil plants studies and the most relevant in terms of current environmental issues relates to the sequence of collapse and recovery of vegetation. We have observed that following the collapse of plant communities in response to climate change, the new communities are recruited or built from the existing communities. For example, species that had once played a minor ecological role in Late Triassic communities became the dominant ecological plants in the Jurassic. This observation challenges the prevailing idea that invasive species from other geographical areas will play an important role in future ecosystems responding to future climate change. Instead we predict, based on fossil plant evidence, that future ecosystems, in the most part, will be composed of the same species that are present today but they will have vastly different ecological roles. The dominant native Irish forest species of our current ecosystems may be relegated to a lesser ecological role, whilst the species today with are less common may become the dominant forest type. Our analyses of past vegetation responses to climate change also suggest that species which are specialized, in that they require another organism to complete part of their life cycle, will be more prone to going extinct than more generalist species.

1. Péac: Programme for Experimental Atmospheres and Climate

We combine our palaeobotanical studies of fossil plant responses to past climate change events with an experimental approach using simulated climate and atmosphere chambers. Plant growth and physiological experiments are currently being carried out at UCD in a new state-of-the-art facility called Péac. This facility can simulate any climatic, light or atmospheric environment from the past, present or future.

Figure 5 – .Péac laboratory at UCD consisting of six CONVIRON walk in plant growth rooms with full atmospheric and climate control.

Currently we are running a suite of experiments where we have simulated a toxic past atmospheric environment from the Triassic-Jurassic boundary. Analogue Late Triassic plant communities are being subjected to elevated carbon dioxide, sulphur dioxide and temperatures in combination with ambient (21%) and low oxygen concentration (13%) in order to elucidate the key triggering factor for mass plant extinction in the Late Triassic.

References

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