Title: Project PEA (Photosynthesis and Earth Atmospheres): Investigating the effect of evolutionary adaptation to high atmospheric carbon dioxide concentrations in fossil and living plants

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Abstract: Photosynthesis is of critical importance to biodiversity, food security and society within the context of current climate change. The photosynthetic responses of plants to rising atmospheric CO_2 have been studied in experiments where CO_2 is artificially enriched to predicted levels. However, these experiments involve plants adapted to current "low" ambient levels of ~380ppm CO_2, and do not incorporate consideration of plant evolutionary adaptation of photosynthesis, where the physiology of plants adjust to long-term incremental CO_2 rises. Plants growing around volcanic CO_2 degassing vents possess an evolutionary adaptation to "high" atmospheric CO_2 and display markedly different responses than plants adapted to lower ambient CO_2. Plants adapted to "high" CO_2 exhibit pronounced photosynthetic rates, no down-regulation of photosynthetic physiology and maintenance of transpiration rates – all important parameters for coupled atmosphere-biosphere models of climate, vegetation and carbon sequestration responses to aid management and mitigation of future climate change. These evolutionary responses to CO_2 are also present in the plant fossil record over timescales of millions of years. The stomata of fossil plants are used to reconstruct past atmospheric levels of CO_2 in the study of previous global-warming events that provide important climate/biodiversity indicators for the current global-warming crisis. The use of living plants adapted to both "high" and "low" atmospheric CO_2, in comparative physiology/morphology studies under elevated CO_2, will provide much needed data on likely plant responses to rising CO_2 and those of plant fossils through earth history. This will place Europe at the forefront of plant evolution and palaeoclimatic research; linking two European research institutions (IBIMET, Italy and Justus-Liebig-Universität Gießen, Germany) in the European Research Area to create a platform for European Research Excellence and competitiveness.

Aims: The aim of Project PEA is to examine multi-generational photosynthetic adaptation in modern plants growing at volcanic carbon dioxide degassing vents and reconstructed photosynthesis during critical periods in earth history marked by climatic change, in order to provide data and predictions of long-term vegetation responses to current global warming.

- Compare photosynthetic and morphological responses of plants with evolutionary adaptation to "high" atmospheric CO_2 (those from volcanic vents) to plants adapted to "low" CO_2. It will do this by studying plants from volcanic CO_2 degassing vents in Italy (Bossoleto, Solfatara di Viterbo, Mefite di Ansanto) to study the effects of long-term multi-generational evolutionary adaptation to "high" CO_2 on plant photosynthetic physiology and morphology.
- Assess the hypothesis that long-term photosynthetic adaptation to incremental CO_2 increases are likely to result in a maintenance / stimulation of photosynthetic capacity that is not associated with a reduction in plant transpirative water loss due to reduced stomatal density sensitivity at "high" CO_2.

• Assess the effect of adaptation to "high" CO_2 on photosynthetic physiology in plants grown under controlled environment conditions in order to: a) quantify long-term adaptational photosynthetic responses of modern plants to an incremental two-fold increase in CO_2 predicted over the next 50-100 years, and; b) develop a novel proxy of plant palaeo-physiology to reconstruct photosynthetic performance during previous global warming events.

Outcomes

• There are many experimental studies into the effect of increased [CO_2] on plant physiology and morphology. These studies involve plants adapted to current [CO_2] of ~400 ppm, and a sudden experimental step-change in [CO_2]; with plants commonly exhibiting reductions in both photosynthetic capacity and transpirational water-loss17. Plants from volcanic CO_2 degassing vents have experienced multi-generational growth in atmospheres of elevated [CO_2]. Plants from these vent populations adapted to 'high' [CO_2] show no down-regulation of photosynthesis nor reduced transpiration when grown in atmospheres artificially enriched in [CO_2] (Fig 1). These ground-breaking findings suggest that predictions of crop and biodiversity responses to future climate change may be erroneous due to a lack of consideration of the role of evolutionary adaptation.

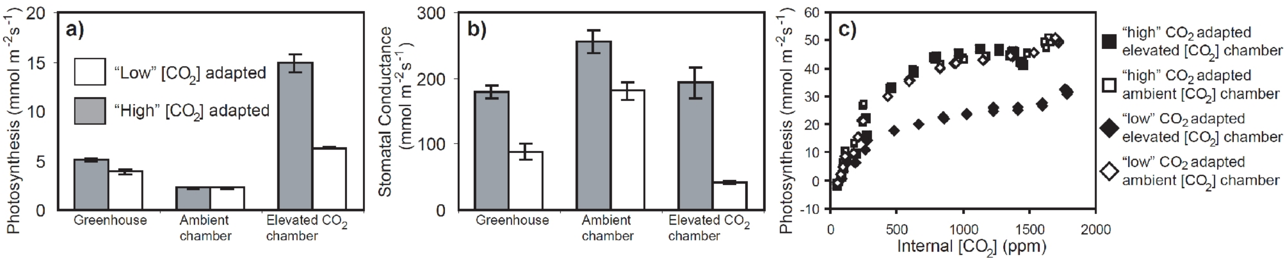

Figure 1: The divergence in photosynthetic and stomatal responses of *Agrostis canina* (a-b) and *Agrostis stolonifera* (c) adapted to current ambient ('low') and 'high' [CO_2] when grown in atmospheres of ambient (380 ppm) and elevated (1500 ppm) [CO_2]. 'High' [CO_2] adapted plants show enhanced photosynthetic rates (a), increased transpiration (b) and no down-regulation of photosynthetic physiology (c) in comparison to plants adapted to current ambient 'low' [CO_2] (Haworth *et al*. 2010; Haworth *et al*. In Preparation).

The Giessen Free Air Carbon Enrichment (GiFACE) study is the world's second longest running FACE experiment, operating moderate 20% [CO_2] enrichment continuously for 15 years. The [CO_2] enrichment regime, in conjunction with the extended duration of operation, make the GiFACE study one of the most realistic simulations of the effects of predicted [CO_2] rises on future vegetation responses. In contrast to previous FACE studies that operate higher [CO_2] enrichment regimes, we observed no significant effect of elevated [CO_2] on plant photosynthetic physiology, leaf gas exchange or stomatal morphology. These are crucial parameters in gauging future vegetation responses to climate change for crop and climate modellers, in addition to policy makers. However, meta-analysis suggests an underlying trend across the population towards a reduction in G_s, possibly associated with decreased stomatal size in atmospheres of elevated [CO_2], which may become increasingly apparent at higher [CO_2]. On-going analysis of the grassland experiencing FACE conditions is required over future years in order to identify potential 'tipping-points' where either the photosynthetic physiology or gas exchange characteristics of the vegetation may exhibit a significant response to rising [CO_2].