Physiological performance of seedlings in a temperate FACE forest

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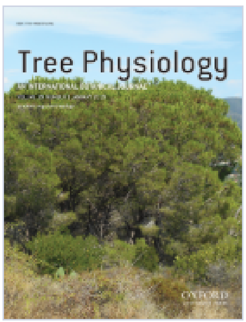

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Influence of elevated CO_2 on growth and physiological performance in seedlings from a mature temperate forest

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Abstract

In a changing climate, understanding the behaviour of tree species subjected to elevated CO_2 is crucial to predicting the future of forest ecosystems. We selected the five most representative tree species coexisting in a mature, unmanaged, temperate, oak-dominated, Free-Air Carbon dioxide Enriched (FACE) experimental forest to assess their performance during one growing season. We measured leaf-level physiological traits, growth and survival on naturally regenerated seedlings found across the experimental site. We also introduced self-irrigated potted seedlings from the same five species into the experimental site in order to have an estimation of the physiological baseline of these species under more controlled conditions and elevated atmospheric CO_2. Empirical non-linear models were fitted to each seedling to describe the temperature effect on photosynthetic capacity. More than one hundred and fifty combinations of ecologically meaningful parameters (A_{max} at saturating light and T_{opt}) were obtained. Under field water capacity (potted seedlings), the five species showed similar photosynthetic capacity under both ambient and elevated atmospheric CO_2. However, natural oak, hawthorn, and holly seedlings exhibited higher maximum photosynthetic capacity (A_{max}) under elevated CO_2, suggesting a positive effect of increasing CO_2 on A_{max} with decreasing soil moisture. The optimum temperature to maximize photosynthetic capacity was similar between species and CO_2 conditions in both natural and potted seedlings, excepting in naturally regenerated sycamore seedlings. Under the forecasted scenario of increasing CO_2, our preliminary results suggest a competitive advantage of species able to maximise photosynthetic capacity at the regeneration stage under drier conditions with elevated CO_2 over the other species.

Introduction

Long-lived trees are particularly vulnerable to changes in climatic conditions since their migration

1) **Background**

2) **Material & Methods**

3) **Preliminary results**

1) **Background**

2) **Material & Methods**

3) **Preliminary results**

Main advantages of FACE experiments:

1. Tree growth capacity under elevated CO_2

- Direct methods: i.e. Dendrometers
- Other methods:
  - ➢ Modelling of root growth, non-destructive method (Clare Ziegler)
  - ➢ Looking at sap flow (Susan Quick)
  - ➢ CO_2 assimilation capacity of adult oak trees (Anna Gardner)

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     - CO_2 assimilation capacity of adult oak trees (Anna Gardner)
2. Tree competition
   - Differences between coexisting species

Rationale

1. eCO_2 is expected to increase leaf photosynthetic rates, but **the degree to which this will actually occur is unclear:** photosynthesis depends on abiotic factors (**leaf temperature, and water and nutrient availability**).

2. eCO_2 might induce greater **nutrient deficiency.**

Rationale

3. Overall, seedlings are more sensitive to stress and/or environmental variations than adult trees.

4. eCO_2 have been shown to modify competition among plant species.

5. The CO_2 assimilation capacity of **coexisting species could be differently affected** by increasing CO_2 which could **alter the forest dynamic**.

Hypothesis

Does the CO_2 assimilation capacity of coexisting species improve under eCO_2 at the seedling stage?

If so, is the positive effect of eCO_2 on assimilation capacity kept under more limiting environmental conditions (i.e. low soil moisture or higher temperature)?

1) Background

2) Material & Methods

3) Preliminary results

Natural seedlings

- ✓ The experiment started in **July**
- ✓ **Naturally regenerated current-year seedlings** were identified and marked across the experimental site
- ✓ 5 main tree species showed relatively good representation in both treatments (ambient and elevated CO_2)

Acer pseudoplatanus (sycamore)

Corylus avellane (hazel)

Crataegus monogyna (hawthorn)

Ilex aquifolium (holly)

Quercus robur (oak)

- ✓ A total of 244 natural seedlings were marked and monitored

Potted seedlings

- ✓ 120 current-year potted seedlings from the 5 species were introduced into the experimental site.
- ✓ They were kept at field water capacity.
- ✓ Estimation of the physiological baseline of these species under more controlled conditions.

4 seedlings x 5 species x 6 arrays =120 pots

Measurements

- ✓ Leaf gas exchange (An at saturating light, stomatal conductance and transpiration).
- ✓ Photochemical efficiency of photosystem II (Fv/Fm)
- ✓ Chlorophyll content
- ✓ Stem diameter
- ✓ Height
- ✓ **5 campaigns (from late-July until mid-October)**

Data analyses

Briere model (1999)

The Briere model has been used to relate leaf photosynthetic rate (A) to leaf temperature (T) through a temperature response curve defined by three parameters

$$A(T) = k_1 T (T - T_{min}) \sqrt{(T_{max} - T)},$$

where

$$k_1 = {A_{max}}/{\left[T_{opt}(T_{opt} - T_{min})\sqrt{T_{max} - T_{opt}}\right]}$$

and

$$T_{min} = \frac{T_{opt}(5T_{opt} - 4T_{max})}{3T_{opt} - 2T_{max}}$$

Expanded model

$$A(T) = (Amax\ /\ [Topt\ (Topt - ((Topt\ (5Topt - 4Tmax\ )\ )/(\ 3Topt - 2Tmax\ )))\ \sqrt{}(Tmax - Topt\ )]\ )T(T - ((Topt\ (5Topt - 4Tmax\ )\ )/(\ 3Topt$$

- ✓ Optimum temperature ***Topt* (°C)**
- ✓ Maximum gross photosynthetic rate ***Amax* *(µmol CO_2 m^{-2} s^{-1})***
- ✓ Maximum temperature **(*Tmax*)=32°C**

Model fitted to each seedling

Potted seedlings

✓ 97 combinations of parameters Amax and Topt obtained

↓

No water deficit

- **Plants were kept at field capacity**

≠

Natural seedlings

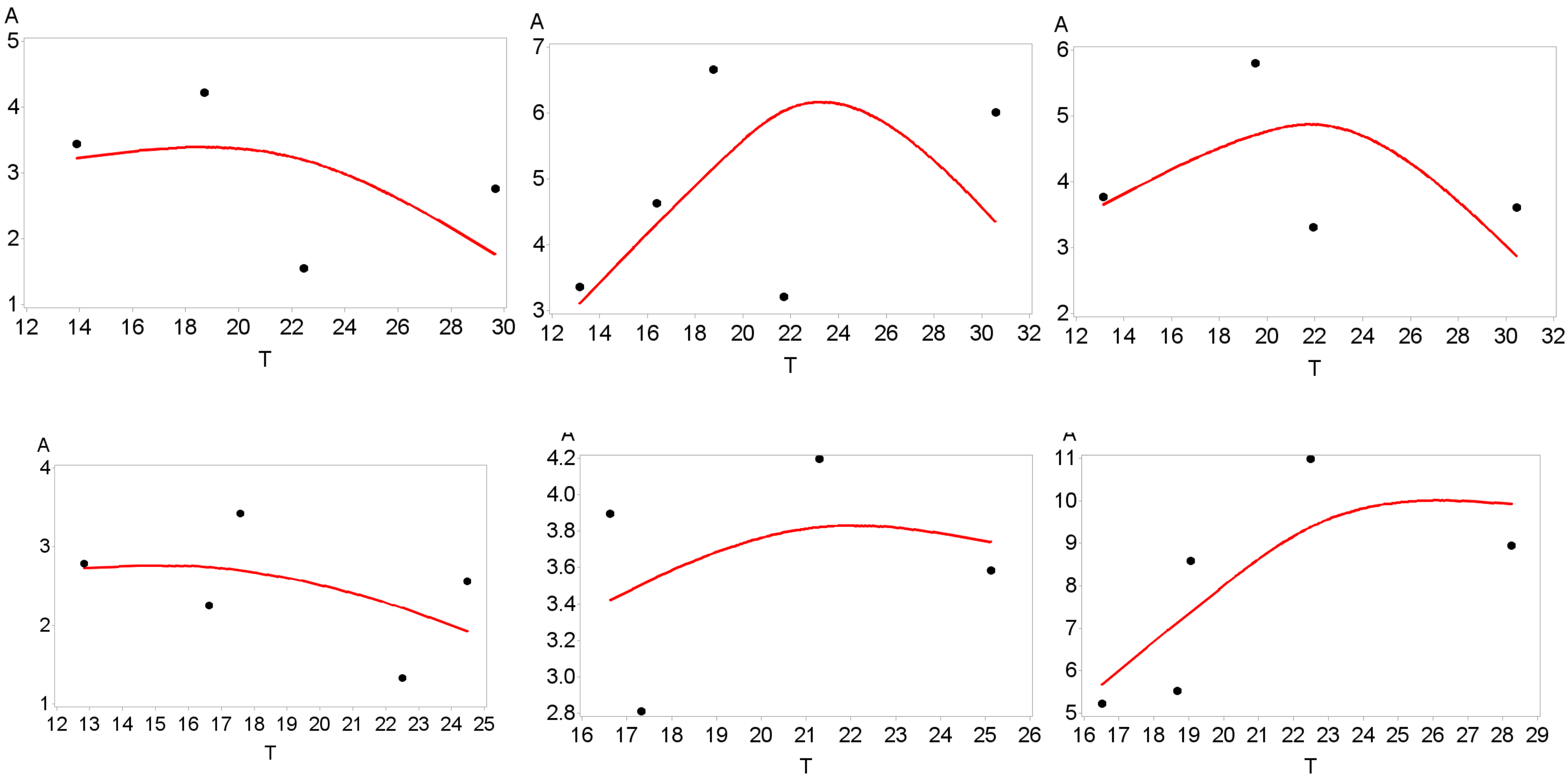
✓ 78 combinations of parameters Amax and Topt obtained

↓

Natural soil moisture

- **heat wave 2018 +**
- **low soil moisture in the upper soil layers**
- **Shallow root systems**

A-T response curves examples

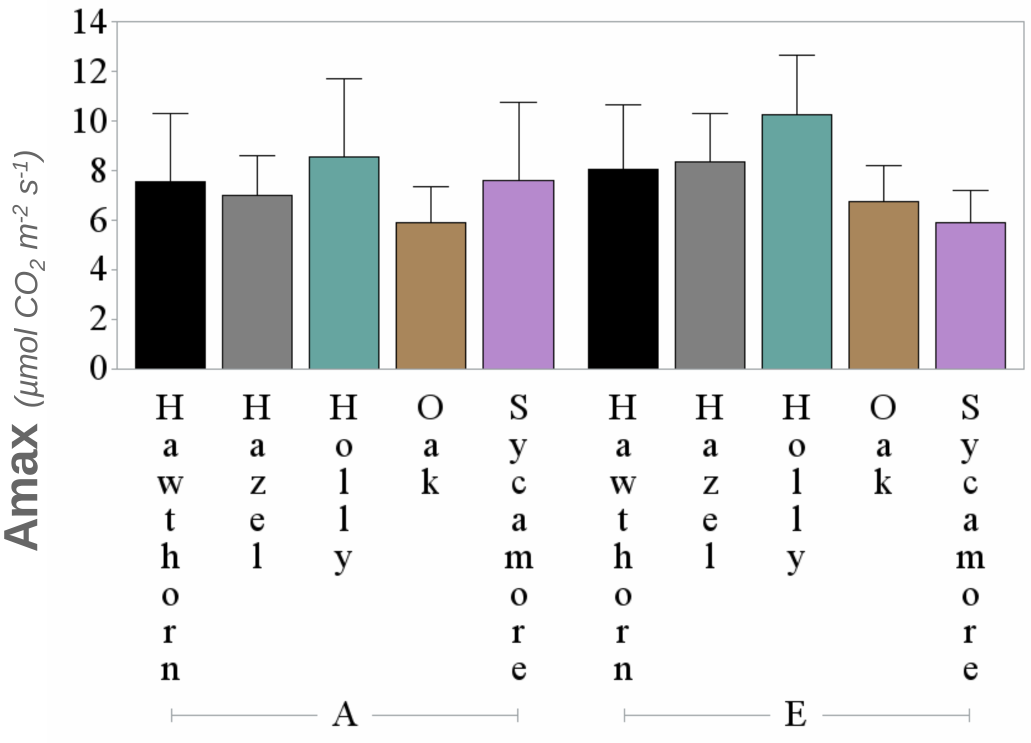


1) Background

2) Material & Methods

3) **Preliminary results**

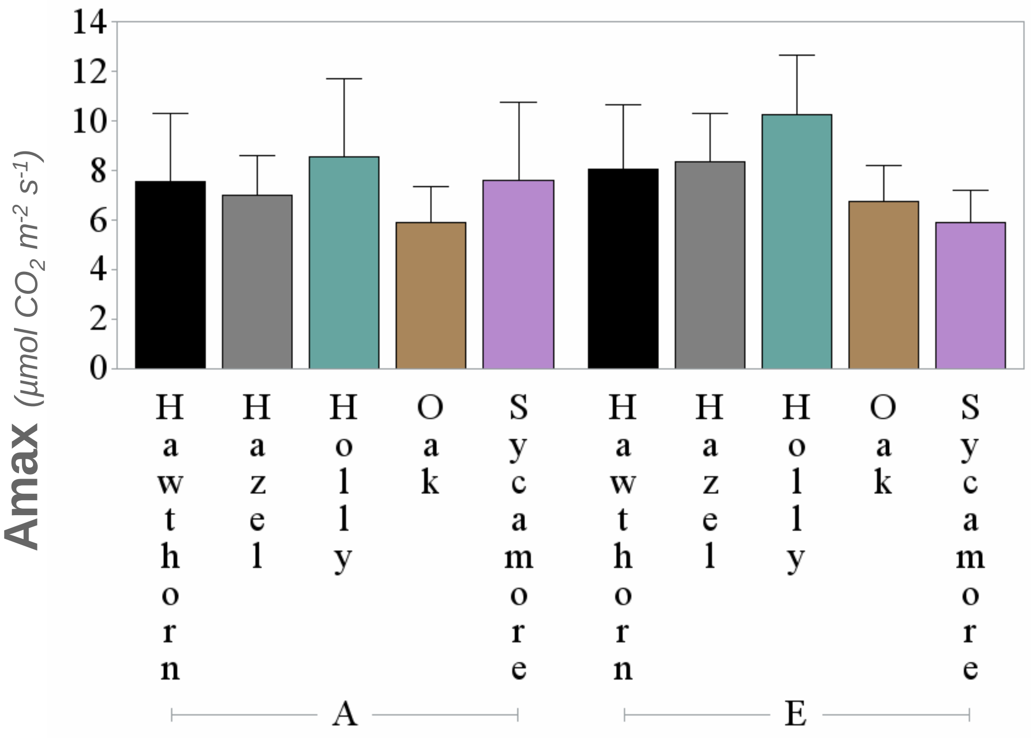
Maximum photosynthetic capacity potted seedlings



Type 3 tests of fixed effect

	num DF	F value	P>F
treatment	1	3.41	0.0683
species	4	3.48	0.0111
treatment*species	4	1.29	0.2795
cov stem diameter	1	2.74	0.1014

Maximum photosynthetic capacity potted seedlings

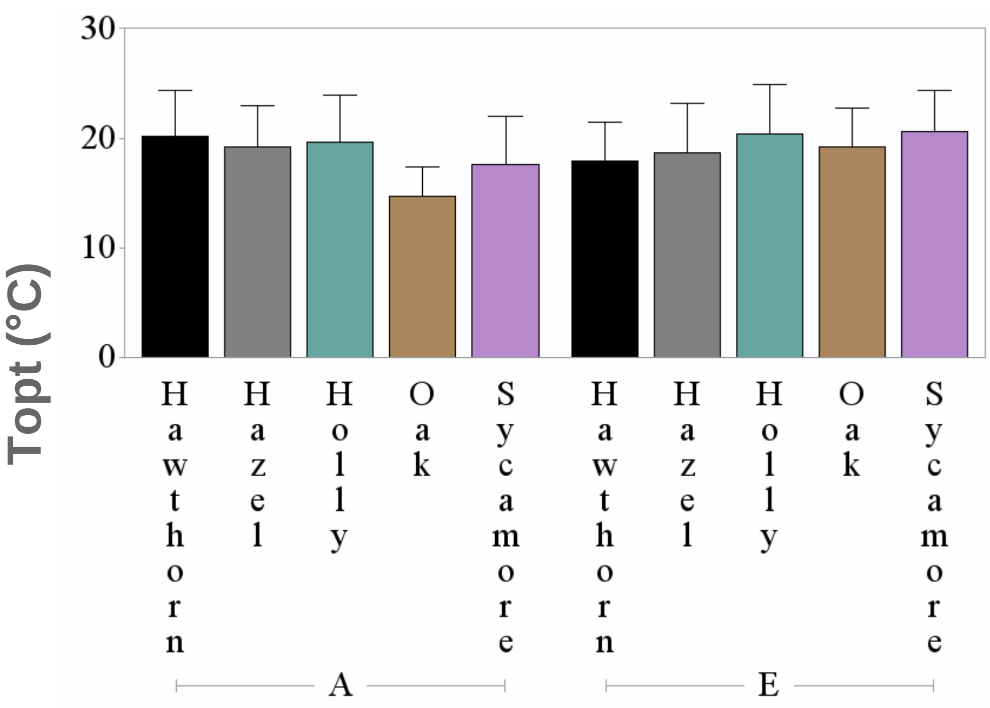


Type 3 tests of fixed effect

	num DF	F value	P>F
treatment	1	3.41	0.0683
species	4	3.48	0.0111
treatment*species	4	1.29	0.2795
cov stem diameter	1	2.74	0.1014

- ✓ No statistical differences for a same species under different treatments
- ✓ Overall sycamore showed lower Amax than holly and hawthorn
- ✓ Parameter mean diameter (D) was included as a size covariate, there was not effect of D on Amax

Optimum temperature potted seedlings

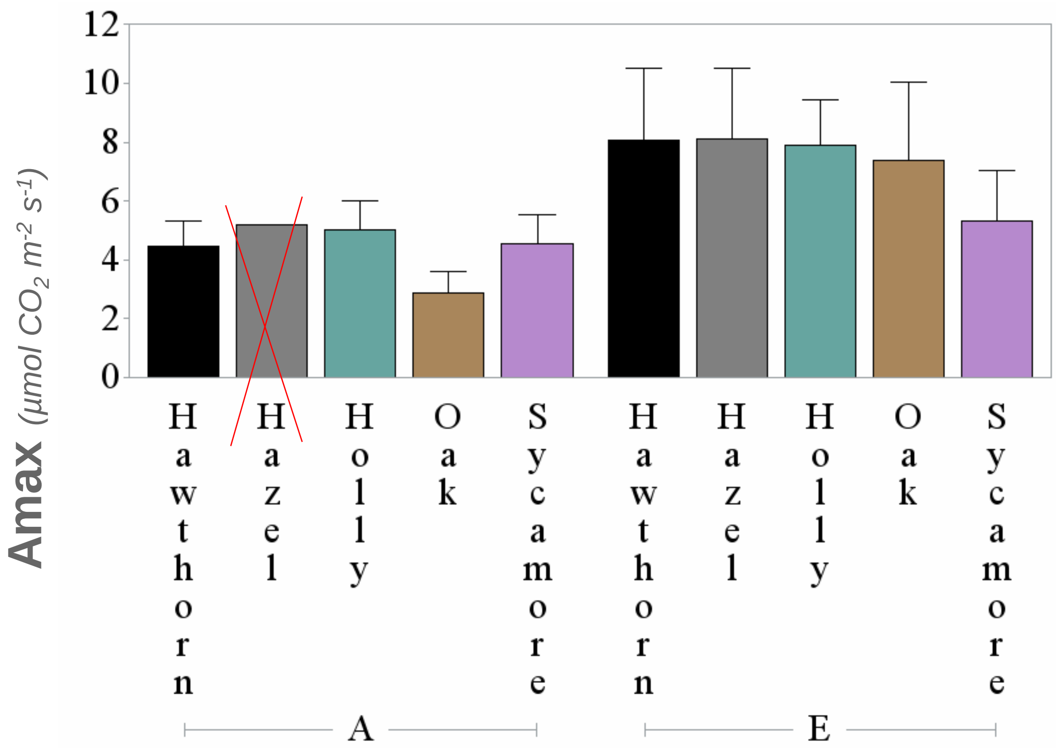


Type 3 tests of fixed effect

	num DF	F value	P>F
treatment	1	0.13	0.7202
species	4	1.02	0.4037
treatment*species	4	1.67	0.1649
cov stem diameter	1	0.23	0.6309

- ✓ No statistical differences under different treatments

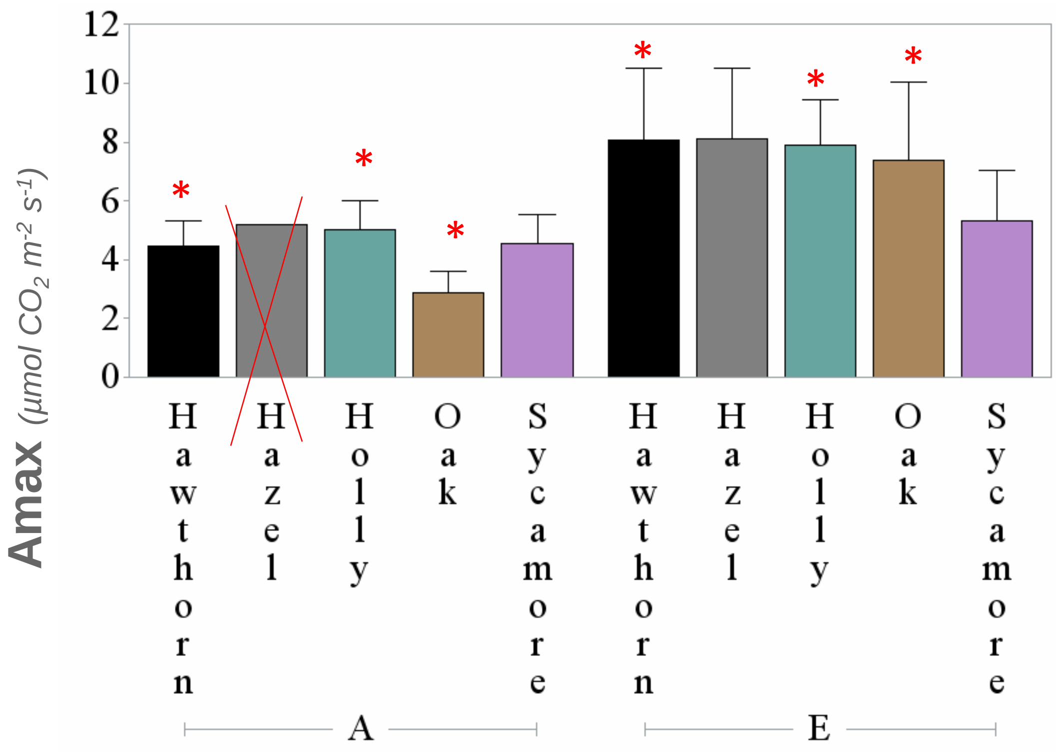
Maximum photosynthetic capacity natural seedlings



Type 3 tests of fixed effect

	num DF	F value	P>F
treatment	1	13.11	<0.0001
species	4	7.46	0.0143
treatment*species	4	3.25	0.2524
cov stem diameter	1	7.39	0.0179

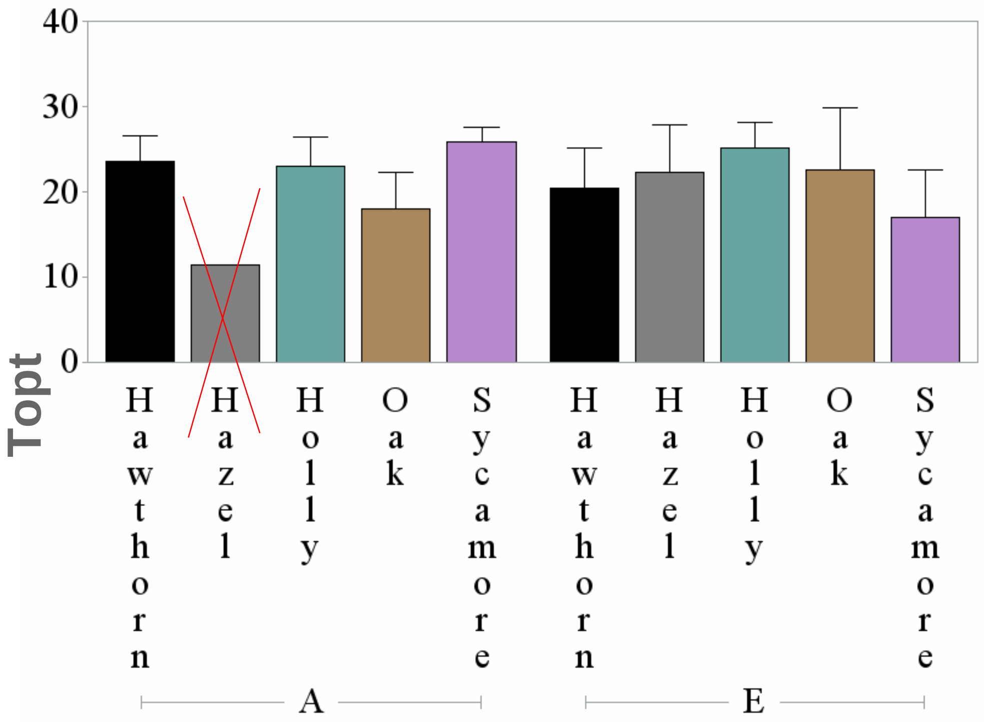
Maximum photosynthetic capacity natural seedlings



Type 3 tests of fixed effect	num DF	F value	P>F
treatment	1	13.11	<0.0001
species	4	7.46	0.0143
treatment*species	4	3.25	0.2524
cov stem diameter	1	7.39	0.0179

- ✓ Under elevated CO_2 hawthorn, holly and oak showed higher maximum photosynthetic capacity than under ambient CO_2 (*)
- ✓ The covariate stem diameter had a significant effect on Amax
- ✓ Natural sycamore did not respond to elevated CO_2

Optimum temperature natural seedlings



Type 3 tests of fixed effect

	num DF	F value	P>F
treatment	1	0.56	0.4588
species	4	1.93	0.1349
treatment*species	4	0.47	0.0012
cov stem diameter	1	1.74	0.1398

- ✓ Natural sycamore showed lower optimal temperature to maximise photosynthesis under eCO_2

Synthesis

Under field water capacity (potted seedlings), the five species showed similar photosynthetic capacity under both ambient and elevated atmospheric CO_2. However, natural oak, hawthorn, and holly seedlings exhibited higher maximum photosynthetic capacity (Amax) under elevated CO_2, suggesting a positive effect of increasing CO2 on Amax with decreasing soil moisture

Conclusions

- Under the forecasted scenario of increasing CO_2, our preliminary results suggest a competitive advantage of species able to maximise photosynthetic capacity at the regeneration stage under drier conditions with elevated CO2 over the other species.

Next steps:

- Apart from these positive effects, elevated CO_2 might induce greater nutrient deficiency, this could be the case of sycamore: To assess the relationship between Amax and soil nutrients: **In progress**

- To fit the coupled photosynthesis-stomatal conductance model of Medlyn et al. 2011: To determine the marginal water cost of carbon gain for these species: **In progress**

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Thanks!

Looking forward to hearing your questions ☺

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