# ANNEX 1:
# Report on work carried out at the Forest Research open top chamber facility at Headley nursery in 2002-03

## 1. Introduction

This report details the work carried out at the FR Open Top Chamber (OTC) facility at Headley. The experiment was originally established to determine the effect of elevated carbon dioxide ($CO_2$) and ozone ($O_3$) on stomatal conductance under conditions of water deficit that are likely to be experienced in southern England by the latter part of this century according to the UKCIP98 'Medium-High' climate change scenario. The work was commissioned to corroborate the preliminary findings of Heath (1999), which indicated that exposure to elevated concentrations of carbon dioxide impaired the ability of stomata to close in response to soil water and leaf-air vapour pressure deficits. Six tree species have been exposed to factorial combinations of the two gases, with four replicate species for each treatment combination. The six species are *Acer pseudoplatamis*, *Fagus sylvatica*, *Nothofagus obliqua*, *Pseudotsuga menziesii*, *Pinus nigra* & *Quercus robur*. Growth data have also been collected, which will provide further data-sets for the derivation of robust dose response relationships as described by Karlsson *et al*. (2003).

## 2. Fumigation control

Fumigation control has, in general, been satisfactory, although technical problems did result in control falling outside the target concentrations of 600 ppm $CO_2$ and 80 ppb $O_3$ from 12:00 to 16:00 GMT. The $CO_2$ supply was exhausted on days 127-130, 225-226 and 259-261. Control system failure resulted in 800 ppm CO2 and 120 ppb exposure on days 238-240 and 269-270. Air conditioner and compressor failures resulted in no ozone exposure on days 189-197 and 211-213. The diurnal course of CO2 and O3 concentrations during the ozone exposure period (day 100 to 262) are shown in Figure 1, with individual mean concentrations over this same period given in Table 1.

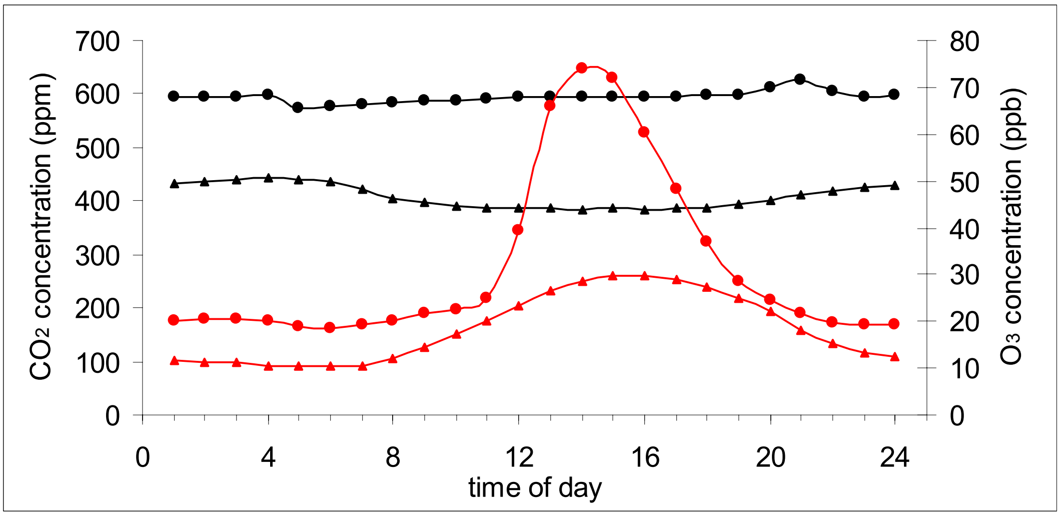


**Figure 1.** 2002 mean hourly $CO_2$ and $O_3$ concentrations (day 101-262)

**Table 1.** Mean $CO_2$ and $O_3$ concentrations during the ozone exposure season (day 101-262) for 2002 for each chamber at the Headley OTC facility.

| **chamber** | **2** | **3** | **9** | **10** | **5** | **8** | **11** | **14** | **4** | **6** | **15** | **16** | **1** | **7** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **treatment** | ambient | | | | ozone | | | | carbon dioxide | | | | carbon dioxide + ozone | | | |
| **$CO_2$** | 412 | 407 | 406 | 411 | 409 | 412 | 407 | 412 | 595 | 595 | 593 | 594 | 595 | 595 | 594 | 594 |
| **$O_3$** | 18.4 | 17.8 | 18.1 | 18.8 | 31.3 | 31.3 | 31.7 | 30.8 | 16.9 | 16.1 | 17.9 | 16.8 | 30.7 | 31.5 | 31.6 | 29.7 |

## 3. Measurement protocols

At the end of the 2001, a complete harvest of sycamore and *Nothofagus* had been carried out, as both species had outgrown the chambers in the elevated $CO_2$ treatments. These two species were allowed to re-grow as coppice, with both survival and biomass production assessed at the end of the 2002 growing season.

In October 2002 the annual non-destructive assessment of stem height and diameter (above the root collar) was completed for all trees of all six species in each chamber. An estimate of stem volume was made on the basis of the stem being represented as a cone ($^1/_3\pi r^2 h$). The estimate of stem volume was used to identify for each chamber and each species, the smallest, largest and median tree. The three trees were identified and harvested according to the protocol developed for the EU FP5 MEFYQUE project. Stem and branch fresh weights were recorded for all fractions and the material subsequently dried for a minimum of 48 h at 75$^o$C or to constant weight. Anatomical and structural analysis is currently being carried out by colleagues at BRE (Watford), the University of Gent, and the Technical University of Berlin. No assessment was made of leaf or root biomass.

Stomatal conductance data collected during the 2001 growing season were augmented by additional data collected for the four deciduous species. It should be noted that data presented for sycamore and *Nothofagus* represent coppiced trees. Stomatal conductance measurements were made using a Ciras-1 gas exchange analysis system (PP-systems, Hitchin, Herts). All measurements were made between 09:00 and 14:00 h GMT.

## 4. Results

The following section displays graphically the results that have been obtained. Error bars in all cases represent the standard deviation of the data set with the chamber as the experimental unit. No statistical analysis has been performed on the data to date.

### *4.1 Stem dry weight and allometric relationships*

Allometric relationships between stem dry weight and volume were derived by linear regression on the basis of the three trees per chamber and species harvested in 2002 (Figure 2). The correlation between dry weight and volume is good for the two broad leafed species, and surprisingly poorer for the two conifer species.

The two species that are not shown in Figure 2 are *A. pseudoplatamis* & *N. obliqua*. Both were harvested at the end of the 2001 growing season, and subsequent re-growth was extremely variable with a large number of shoots typical of coppice. Allometric relationships, although available from the earlier harvest cannot be applied because of the change in growth form.

The allometric relationships described above were used to model stem woody biomass for the individual trees that were not destructively harvested. This data set was then combined with the harvest data in order to asses the effects of the individual treatments (Figure 3). Stem dry weights for sycamore and *Nothofagus* are for the harvest following the 2001 growing season.

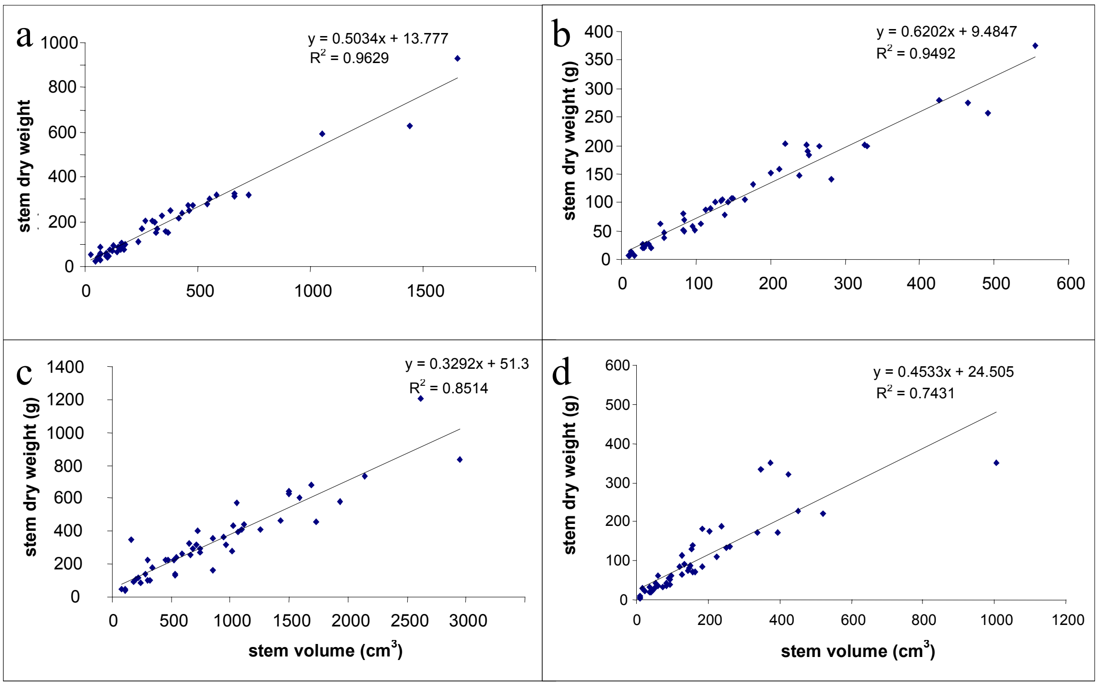


**Figure 2.** Allometric relationships between stem volume and stem dry matter (a) *Quercus robur*, (b) *Fagus sylvatica*, (c) *Pseudotsuga menziesii* & (d) *Pinus nigra*.

The clearest treatment effects were for elevated $CO_2$ to which all species responded positively, with the exception of oak which had variable responses to all treatments. The response of beech was typical of the responses to both treatments that would be expected based on reported findings in the scientific literature; the elevated $CO_2$ treatment led to a significant enhancement of growth and ameliorated the negative effects of ozone that were observed at ambient $CO_2$. No $CO_2$ induced growth enhancement was seen in Douglas fir, but Corsican pine, *Nothofagus* and sycamore all showed a positive effect of $CO_2$ on growth. The most interesting result is the observation that in the two fastest growing species (sycamore and *Nothofagus*), ozone had no effect on growth at ambient $CO_2$, but enhanced growth at elevated $CO_2$. This may reflect impaired stomatal function, and an inability to close in response to elevated $CO_2$. Under good growth conditions, this may be beneficial, but may make these two species more vulnerable to drought related mortality. It should be noted that the growth reported for these two species is for two growing seasons, as opposed to three for the other four species. In general, treatment effects are less consistent than reported the previous year, possibly reflecting the onset of resource limitation (nutrient or light).

Further data analysis, including a full statistical after the final harvest may cast further light on the treatment interactions, and these results should only be viewed as preliminary. Further quality control of the data is also required. Survival and biomass production at the chamber level is given for the two coppiced species in Table 3. No treatments effects are evident for either measure, and the 'stools' are only to be retained to provide plant material for further gas exchange analysis.

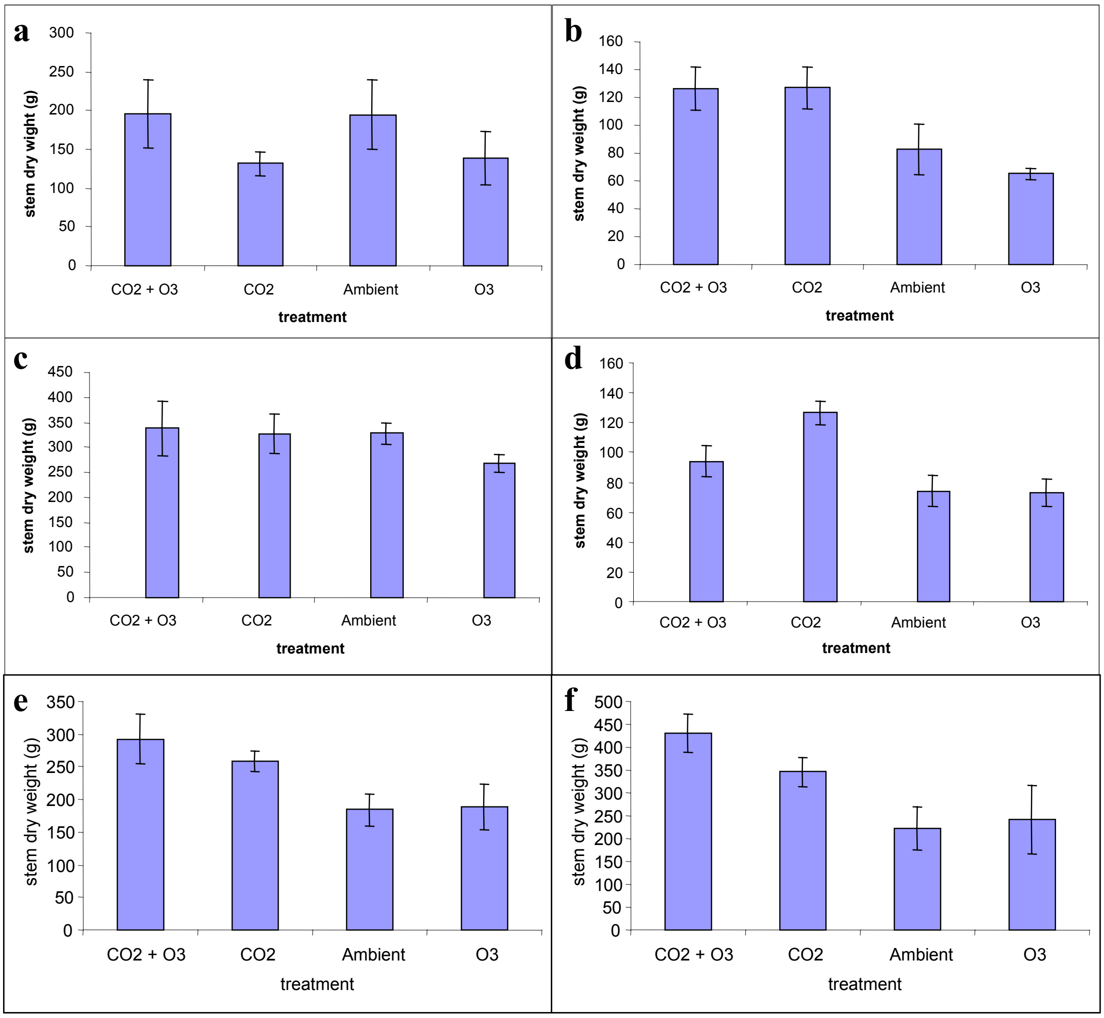


**Figure 3.** Treatment effects on stem dry weight for (a) *Quercus robur*, (b) *Fagus sylvatica*, (c) *Pseudotsuga menziesii*, (d) *Pinus nigra*, (e) *Acer pseudoplatamis* & (f) *Nothofagus obliqua*.

**Table 3.** Survival and biomass production for sycamore and *Nothofagus*. Data represent growth over one season following coppicing in winter 2001-2.

| Treatment | Stool survival (%) | | | | Biomass production per chamber (g) | | | |
|---|---|---|---|---|---|---|---|---|
| | amb | O3 | CO2 | CO2+O3 | amb | O3 | CO2 | CO2+O3 |
| Nothofagus | 54 | 71 | 71 | 71 | 54 | 71 | 71 | 71 |
| Sycamore | 83 | 71 | 83 | 79 | 445 | 270 | 396 | 418 |

### *4.2 Stomatal Conductance*

Stomatal conductance measurements were made during the 2001 and 2002 growing season for all four of the broad-leaved species present. The data presented here (Figure 4) was measured under ambient light conditions with no additional light source being used. As Figure 4 demonstrates, a reduction in $g_s$ (as compared to ambient) was seen across all four species under the $CO_2 + O_3$ treatment, in addition $CO_2$ alone reduced $g_s$ in three out of the for species, with only *F. sylavatica* not following this pattern. This latter observation does appear to confirm the findings of Heath and Mansfield (1999), suggesting that beech may be vulnerable to drought at enhanced concentrations of $CO_2$. It is interesting to note that the largest reduction in $g_s$ under the $CO_2 + O_3$ treatment was in *A. pseudoplatamis* and *N. obliqua*, the two fastest growing species and also those species for which ozone appeared to enhance growth at elevated CO2 concentrations. It is difficult to reconcile these observations, and further measurements and analysis will be undertaken in 2003-4. It is also interesting to note that beech, which is regarded as sensitive to ozone, was observed to show a significant increase in conductance at elevated $CO_2$, although not in the combined treatment.

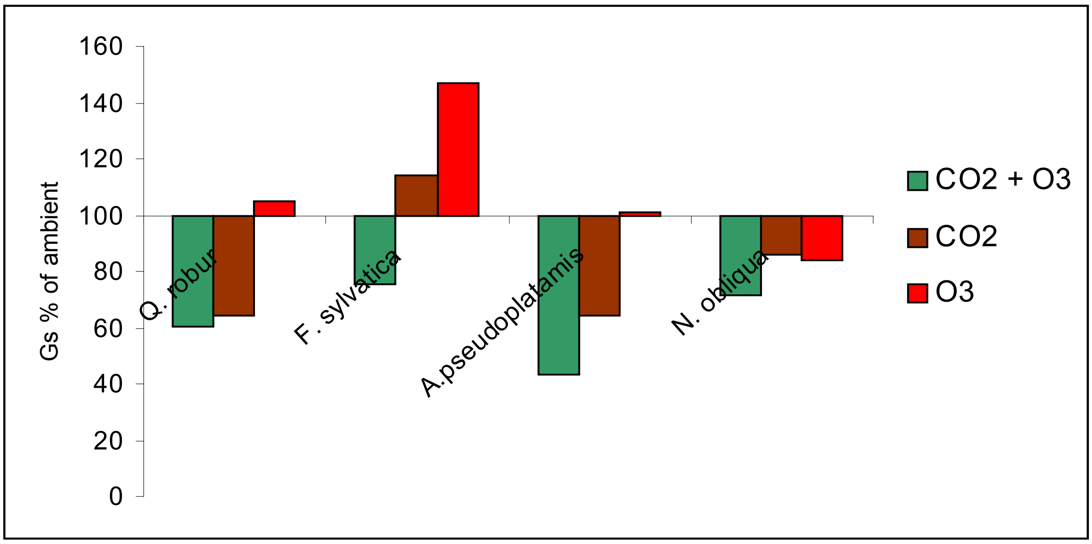


**Figure 4.** Stomatal conductance for the broad-leaved species expressed as a percentage of the ambient mean.

***4.3 Ozone Flux***

Data from this experiment along with previous experiments at Headley are being used to generate ozone dose-response relationships using biomass accumulation of young trees as the measure of effect (Karlsson *et al.* in press). Observed reductions in biomass production in response to ozone have been related to ozone uptake, modelled from climate data, and measured values of maximum conductance. These data-sets have been used in defining new Critical Levels/Loads for ozone as part of the revision of the UN-ECE mapping manual prior to the revision of the Gothenberg protocol in 2005.

Leaf or needle ozone uptake was estimated using the multiplicative stomatal conductance simulation model of Emberson *et al*. (2000) as used within EMEP to model deposition of ozone and thus ozone concentrations at a European scale. The EMEP parameterisation of the model was used, except for the soil moisture function which was based on conventional soil physics, and maximum stomatal conductance in oak, which was based on measurements at Headley. Further details are given in Karlsson *et al*. (2003), and the figures on which the new critical levels are based are given in Figure 5. The new dose-response relationships were also compared with exposure-response relationships based on daylight AOT40 (accumulated ozone dose above 40 ppb.

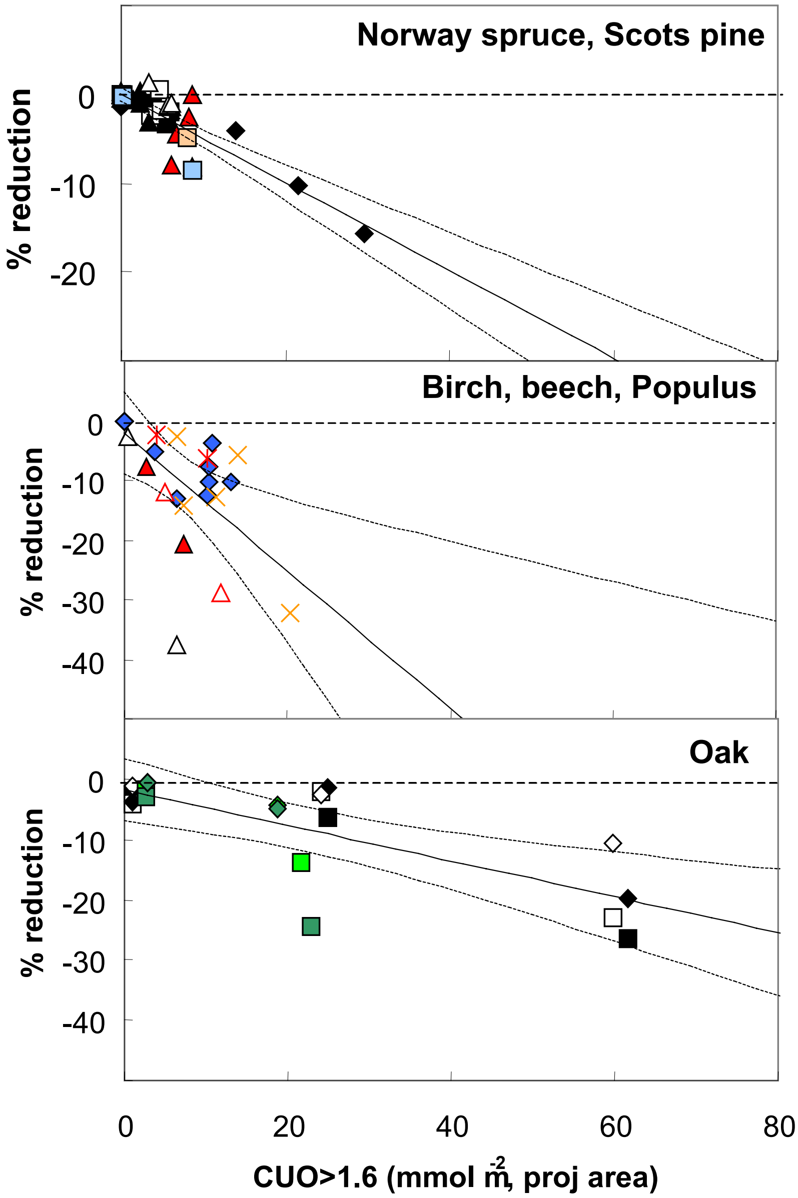


**Figure 5.** Relationships used to derive new flux-based Critical Levels for ozone as part of the revision to the UN-ECE mapping manual. Different symbols refer to different experimental facilities/sites. Norway spruce and Scots pine are characterised as ozone sensitive coniferous species, and birch/beech/poplar and oak as ozone sensitive and tolerant deciduous species, respectively. (Karlsson et al. (2003).

## 5. Work programme for 2003-4

- Continue with physiological studies including comprehensive campaign of stomatal conductance measurements to incorporate *P. menziesii* and *P. nigra*.
- Harvest remaining trees at end of growing season; assessment to be made of below ground biomass.
- Data from the 2000-2004 experiment will be manipulated to provide further data-sets for improving the robustness of the dose-response relationships given in Figure 5.