A wood for the future

Site selection and establishment for the Birmingham Institute for Forest Research (BIFoR) free-air carbon dioxide enrichment (FACE) facility

Authors: Rossa Donovan,[1] Liz Hamilton,[2] Dan Holmes,[3] Rob MacKenzie[2]

Introduction

There is now an overwhelming consensus amongst scientists that increased atmospheric carbon dioxide (CO_2) as a result of human activity is contributing to rising global temperatures. Carbon dioxide levels in the atmosphere now average 400 parts per million by volume (ppm) globally, a 40% increase on pre-industrial levels. Understanding the impact of a warmer planet on our environment, and on our society, has therefore been a major focus for scientific research over the past few decades.

At the global scale, numerical modelling of coupled atmospheric-land-ocean models, known as general circulation models (GCMs), has helped us understand how vital systems, such as the hydrological and carbon cycles, or weather patterns might be affected by future changes in atmospheric CO_2 concentrations, or rises in average temperatures. However, downscaling GCMs to predict climate change response at finer scales to include, for example, vegetation feedbacks under elevated CO_2 remains complicated. To combat this, much experimental work on vegetation response to increasing CO_2 has been conducted on individual plants and species within controlled experiments where a limited number of environmental variables are manipulated. Focusing on physiological changes to plants under variable moisture, temperature or CO_2 conditions has improved global food security by identifying which plants would be better suited to future conditions in different parts of the world. Yet controlled experimental manipulations rarely reflect real-world situations, particularly at the ecosystem scale, where interactions between organisms can strongly modify the response to environmental change.

Whole-ecosystem manipulations are an important tool that allows us to integrate changes to ecosystem function with climate change models. However, implementing ecosystem-scale studies presents a number of challenges for scientific investigations. The complex relationships that exist between the soil, plants, fungi, microbes and animals are generally poorly understood, making it difficult to tease out the subtle differences between ‘normal’ ecosystem function and any changes caused by climate change. Then there is the sheer scale of ecosystem-scale experiments, particularly for forest ecosystems, which presents difficulties in terms of experimental design, instrumentation, and cost. Therefore, identifying the right site for such an experiment is of paramount importance given the multiple controls intrinsic in whole-ecosystem manipulations and the considerable investment of both labour and capital.

The Birmingham Institute of Forest Research (BIFoR) is establishing an ecosystem-scale research facility based within an area of mature, semi-natural woodland set within the rural landscape of Staffordshire: the purpose is to investigate the effects of climate change on a mature woodland ecosystem. The core experimental platform in the BIFoR facility will be a free-air carbon dioxide enrichment (FACE) facility. One of only two full-scale forest FACE facilities operating in the world, the BIFoR facility aims to be an internationally leading research platform, addressing four fundamental and interrelated research questions:

1. Does elevated CO_2 increase the carbon storage in a mature temperate deciduous woodland ecosystem?
2. Do other macro- or micro-nutrients limit the uptake of carbon in this ecosystem now, or are they likely to in the future?
3. What aspects of biodiversity and ecosystem structure-and-function are altered under elevated CO_2 and how do these alterations feed back onto carbon storage?
4. How can this woodland best be managed for carbon storage under climate change, and what general lessons can be learnt from BIFoR FACE and the global network of second-generation forest FACE experiments?

Over the coming years, scientists will apply knowledge obtained from measurements taken deep within the soil to above the tree canopy to answer these questions. Automatic sensors and instrumented trees allow measurements to be taken continuously and remotely, over timescales ranging from seconds to decades whilst complementary lab-based research studies are carried out back at the University of Birmingham’s laboratories.

The FACE site

In spring 2013, the opportunity arose to establish a forest FACE experiment somewhere in the UK. The requirement was for a native, wild or semi-natural, deciduous woodland located near the University of Birmingham. A number of sites were considered across the country; the offer of ca. £1M in-kind support from Norbury Estate prompted a closer examination of sites there.

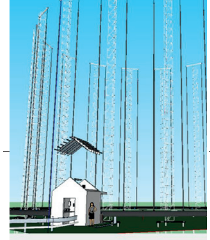
Norbury Park, near Stafford, is a large country estate set within a rural landscape dominated by a mixture of pastoral and arable land uses. Areas of woodland on the estate are typical of those found throughout central England, mostly comprising deciduous, semi-natural or ancient woodland with some more recently planted conifer species. Management of the estate’s woodland blocks has varied historically. Accordingly, a scoping exercise was undertaken to rule out woodland units unsuitable for the experimental plots. A simple qualitative assessment method was conducted, based on the following factors.

1. **Size** – it is desirable to accommodate all experimental plots within the same woodland compartment and therefore the compartment must be big enough to accommodate all plots comfortably. This is important for a number of reasons: the larger

1 WSP Consultants

2 The Birmingham Institute of Forest Research, University of Birmingham, Edgbaston, Birmingham, B15 2TT

3 Estates Department, the University of Birmingham, Edgbaston, Birmingham, B15 2TT



the area of woodland the more likely it is that homogeneous plots can be identified; there are fewer constrictions on optimal plot size in a large woodland; and meteorological and ecological edge effects are likely to have less influence.

2. **Naturalness** – the focus of the research will be on the effects of climate change on naturalistic ecosystems. Therefore woodlands planted with non-native trees should be discounted in favour of those that contain native plant communities.

3. **Homogeneity** – to ensure that experimental results are statistically robust it is necessary to reduce variability between replicate plots. The following factors will be considered during the assessment of the woodland compartments:

    a. **Tree size** – it is desirable for all trees to be the same size due to factors relating to vigour exhibited between different life stages/size categories;

    b. **Topography** – preferably there should be minimal variation in topography between plots as this is likely to affect groundwater conditions and cultural heritage;

    c. **Species composition** – ideally the experimental plots would contain the same species of tree obtained from the same provenance;

    d. **Density** – number of stems per plot would ideally be the same between plots;

    e. **Soil conditions** – differences in soil conditions are likely to have a marked effect on the cultural conditions of each plot and ultimately will have an influence on growth rates and even community structure. Factors such as soil texture, structure and pollutant loading are likely to be important when comparing soils. A comprehensive soil survey of all woodland compartments within the estate was beyond the scope of this preliminary assessment and therefore the assumption was made that a woodland unit would have uniform soil characteristics and therefore be able to accommodate the experimental plots.

4. **Access and utilities** – practical considerations such as site access and distance from power and water supplies will have a bearing on the establishment cost of the facility and thus its viability.

Each area of woodland identified within Norbury Park Estate was assessed as being either suitable or unsuitable with reference to the factors described above. This qualitative approach was combined with a desk study that included a review of publicly available environmental information of the estate and surrounding area. WSP's **iGIS database** was used to synthesise the data, allowing areas to be viewed as OS landline maps, satellite images or terrain maps. Resources used included:

MAGIC (Multi-Agency Geographic Information for the Countryside) database – a GIS-based system detailing administrative geographies, statutory designations, habitats and species, and land-based schemes.

Natural England website – provided information on ecological or geological features in the area considered worthy of protection due to their rarity or exceptional condition.

The Environment Agency website – provided hydrological and hydrogeological information for the site.

The British Geological Survey website and published maps – aided identification of the underlying geology for the area.

From the qualitative analysis of the woodland units, Mill Haft (Figure 1) was the preferred option for a number of reasons. Firstly, Mill Haft is large enough to accommodate nine experimental plots sufficiently distant from the woodland edge to preclude negative meteorological or ecological edge effects. Secondly, the species composition (principally English oak *Quercus robur* standards with an understorey of hazel coppice *Corylus avellana)* is typical of English woodland communities and therefore exhibits a high degree of naturalness. Third, the oak

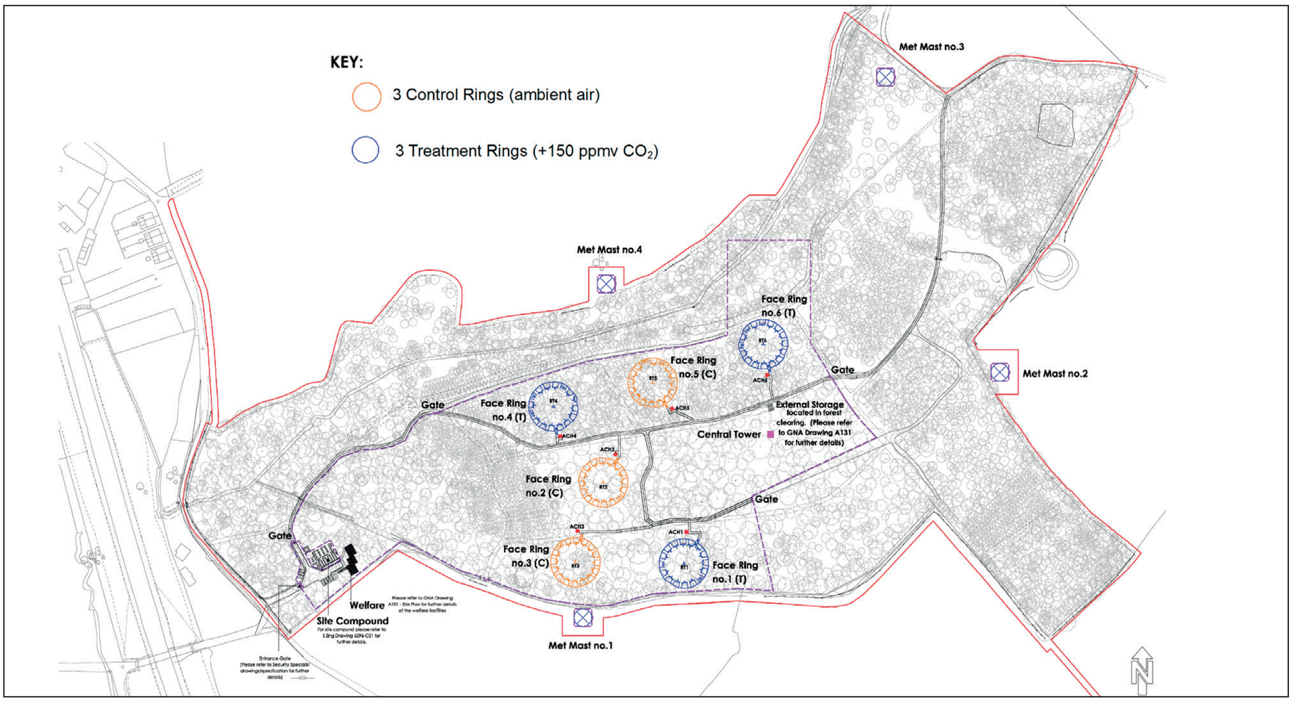
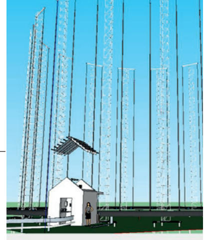


Figure 1. Mill Haft woodland, showing the locations of the major elements of the BIFoR FACE facility.



standards (and presumably hazel stools) appear to have been planted at the same time (ca. 1850), creating a largely even-aged woodland, at least with respect to these two species. Fourth, the woodland is located on low-lying land with little relief; therefore hydrogeological variation is likely to be minimal. Fifth, borehole and trial pit excavations identified relatively uniform organic clayey sand topsoil overlying several metres of glacial till, which in turn sits above the sandstone aquifer of the Bromsgrove sandstone formation. Finally, Mill Haft has good access to the main road and is within a reasonable distance of a water source and power supply.

Installing a FACE experiment in Mill Haft

One of the biggest challenges in setting up BIFoR FACE was designing an experimental facility that doesn't alter the functioning of the woodland ecosystem or cause it to degrade over time. BIFoR's philosophy is to have a 'light footprint' at all times to ensure the baseline conditions of the woodland remain as natural and unaffected as possible. This light touch is absolutely essential to the success of the facility, with careful attention placed on the sensitive proposed siting of its development components; BIFoR FACE will not result in the loss of any significant amount of woodland. The topographical survey and tree survey carried out identify approximately 13,477 trees within the site, of which only 51 are proposed to be removed (equating to approximately 0.4% of the tree population).

The FACE component comprises six vertical structural 'rings' up to 28m in diameter and between 22m and 27m height (Figure 2). A micro-siting principle of up to 5m allows the final location of each FACE ring to be positioned with regard to individual trees during construction, thereby minimising disturbance and loss to the trees. The heights of the FACE rings have been carefully considered to ensure that the majority of the structures are masked by the existing woodland. The potential for views of the proposed development from identified viewpoints was a key consideration during the planning consultation stage for which a considerable amount of 3D visualisation work was undertaken.

Three of the six rings will receive elevated CO_2 treatment (i.e. 150 ppmv above ambient); the remaining three will receive ambient air and act as a control (Figure 1). CO_2 for the three treatment rings is to be piped over ground to the injection frames through the woodland from the compound located close to the site entrance. The control FACE rings will monitor the trees exposed to the ambient air. Comparing the long-term ecosystem response in treatment and control rings will help scientists determine the impacts of the environmental changes on the structure of the woodland.

Throughout the summer, researchers were busy establishing the baseline conditions at the site in terms of atmospheric composition, canopy structure, leaf isotope balance and photosynthetic activity, local hydrology, and invertebrate ecology (Figure 3). Construction of the FACE rings has already begun and is due to finish early in 2016. Following this, the experimental infrastructure will undergo a period of testing, with experiments due to commence in earnest from oak bud-burst in 2016.

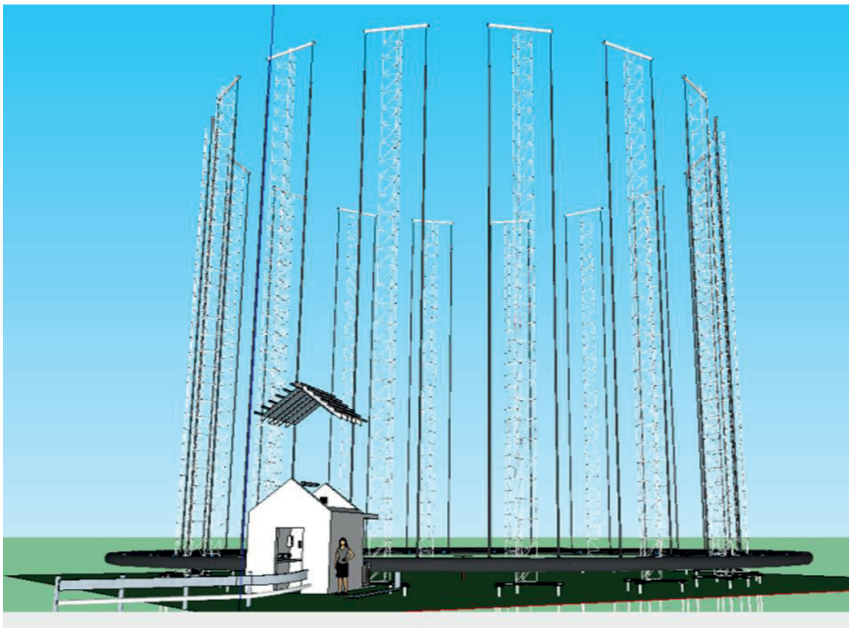


Figure 2. Computer-aided design rendering of a FACE ring in the BIFoR FACE facility. The ring has 28m diameter and is 2m taller tall than the local woodland canopy (ca. 24m). Carbon dioxide gas at ambient temperature is piped from the reservoir (not pictured) to each ring where it is mixed with ambient air to provide an enhancement of 150 parts per million in the air that enters the grey manifold encircling the ring. Air enriched in CO_2 is released into the ring from the pipes on the upwind side of the ring, the wind and CO_2 concentration in the ring being constantly measured from a tower in the centre of each ring (not shown).

Figure 3. A leaf physiology team in Mill Haft, summer 2015. The instrument in the foreground is a Li-Cor 6400, which measures gas exchange of an individual leaf under controlled environmental conditions. Behind the team is the MEWP (mobile elevated working platform) used to access the sunlit oak canopy at >20m. Left to right: Dr Kristine Krous (Distinguished Visiting Fellow), Dr Kris Hart (BIFoR FACE Operations Manager), Prof Rob MacKenzie (Director, BIFoR), Alan Howes (MEWP operator), and Prof David Ellsworth (Distinguished Visiting Fellow). Prof Ellsworth and Dr Krous are from the Hawkesbury Institute for the Environment, where Prof Ellsworth leads the EucFACE facility (www.uws.edu.au/hie/facilities/EucFACE).