

Initial Results from Establishment of a Long-term Broadleaf Monitoring Plot at Wytham Woods, Oxford, UK

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soil & ground flora surveys, dendrometer band installation, April – September 2009.

Data: All data collected from the project are freely available without restrictions.

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1 Introduction

The site of Wytham Woods ($1^{\circ}20'W$, $51^{\circ}47'N$; Figure 1.1) is located approximately five kilometres north west of the ancient university city of Oxford, in southern England. The site was given to Oxford University in 1943 and since then has become one of, if not the most researched woodland in Europe - birds, mammals and invertebrates have been intensively studied here. Now, through the support of the Smithsonian Institution and the financial support of HSBC bank, this site has become the first European site associated with the Smithsonian Institution Global Earth Observatories (SIGEO) programme, a global network that is expanding from its foundations as the Centre for Tropical Forest Science (CTFS) network of tropical forest plots to a number of temperate forest sites. In conjunction with the ongoing ecology work, and with parallel initiatives in carbon cycle studies and satellite remote sensing, Wytham promises to be one of the world's leading research sites in temperate forest ecology and function, and a key long-term observatory that will explore how global atmospheric change may affect this ecology and function.

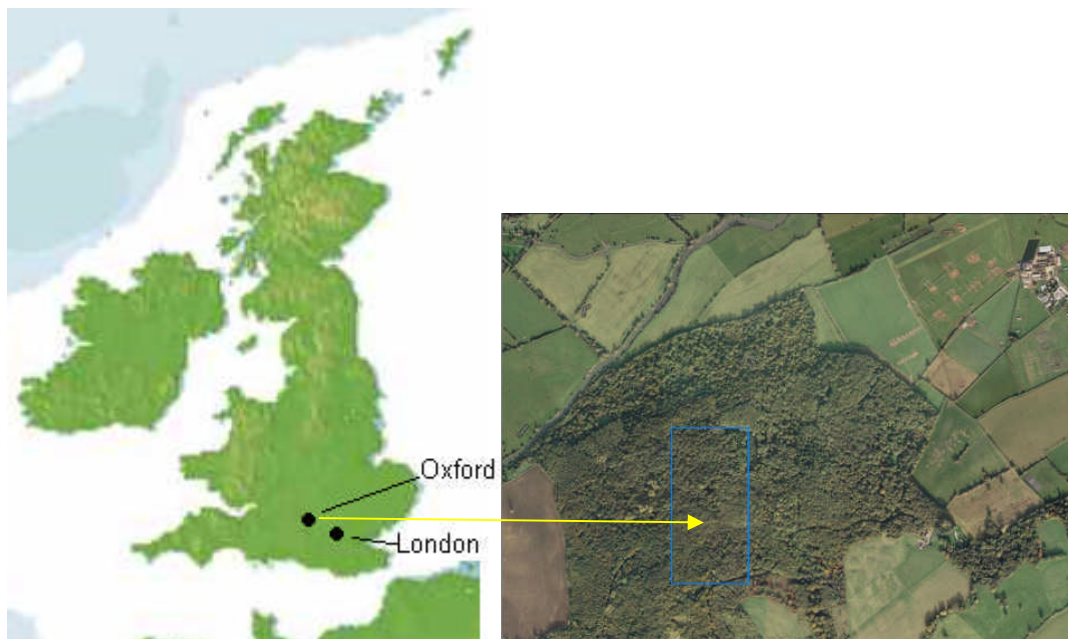


Figure 1.1: location of Oxford and Wytham plot.

Site history & geography

Some parts of the site, including much of Wytham Great Wood, where the SIGEO plot is situated, are ancient woodland in that there has been woodland cover since reliable records and maps began (c.1600): forest cover is assumed to have been present since the end of the

last ice age. Other parts have been pasture or agricultural land at different times and although the ancient parts have been managed for millennia and are thus not truly natural, they have never been clear felled or planted. Wytham has a remarkably rich fauna and flora: more than 500 species of vascular plant have been recorded, though this is probably due to a combination of its size, protected status and the level of biological research – Elton (1966) regarded it as typical of lowland England. For several decades Wytham has been notified as a Site of Special Scientific Interest (SSSI), a conservation designation denoting a protected area in the UK. A forthcoming book (Savill *et al.*, 2010) provides a comprehensive summary of research in Wytham.

In addition to its large badger population, several species of bat, deer, amphibians, and 27 species of earthworm, Wytham hosts a great diversity of insects, with more than 800 recorded species of butterflies and moths; around 8% of which are nationally rare. Brown hairstreak, (*Thecla betulae*), black hairstreak, (*Strymonidia pruni*), and wood white, (*Leptidea sinapis*), butterflies are found in Wytham, as are uncommon moths such as square spot, (*Ectropis consonaria*), brindled white spot, (*E. extersaria*), and maple prominent, (*Ptilodentella cucullina*) - all typically associated with ancient woodland. Many diptera, including Red Data Book species, have been recorded here, along with 900 species of coleoptera (25% of the British population), 200 species of arachnid (about 30% of the British fauna), 700 species of hymenoptera and 250 hemiptera species (SSSI records).

Wytham Woods lies on a variety of neutral clay soils, ranging from thin, freely-draining rendzinas over Corallian limestone at the higher altitudes to poorly-drained deep clay soils at lower altitudes. The site includes areas of different land use histories. These can be categorised as follows (from Morecroft *et al.*, 2008):

- 1) Undisturbed ancient semi-natural woodland: Ancient woodland is woodland which has had a continuity of forest cover since ~ 1600; the period for which historical records are usually available in England (Peterken, 1981). At Wytham, this woodland was managed as a ‘coppice with standards’ system (mixture of coppice stools interspersed with full-height trees). However, coppicing was discontinued over the course of the twentieth century and these areas have been largely unmanaged for between 40 and 100 years (differing locations were abandoned at different times). Hazel (*Corylus avellana* L.) is the most frequent coppice species and pedunculate oak the most frequent standard.
- 2) Disturbed ancient woodland: Ancient woodland areas which were formally managed as coppice with standards, but converted to high forest during the twentieth century. Timber has been extracted at various times but they have not been clear felled. Extensive natural regeneration has occurred, along with some localized planting.

- 3) Secondary woodland: Areas which have naturally reverted to closed canopy woodland over the last 200 years, having previously been grassland or wood pasture (with scattered trees but no continuous canopy). A small amount of localized planting has taken place and there has been some timber extraction.
- 4) Nineteenth-century plantations: Formerly open areas which were planted in the nineteenth century. This planting was largely ornamental with widely spaced trees, particularly of beech (*Fagus sylvatica* L.). Management has been minimal in recent decades.
- 5) Twentieth-century plantations: plantations, mostly of beech and Pedunculate oak, mixed with exotic conifers in some places, planted between 1950 and 1970. Some were planted on grassland and others on cleared ancient woodland areas. Most have been managed by thinning, following standard forestry practice.

The large-scale monitoring plot comprises 18 hectares in the middle of the woodland, arranged in a 300 m x 600 m rectangle, on the side of a hill varying in elevation from around 100 masl to 160 masl. It comprises mostly disturbed ancient semi-natural woodland (category 2 above) with smaller areas of secondary woodland and small scale plantation.

Woodland type & vegetation

The tree and ground flora of Wytham have been extensively studied over decades (e.g., Kirby *et al.*, 1996). The wood falls into the category of W8 *Fraxinus excelsior*–*Acer campestre*–*Mercurialis perennis* woodland, following the National Vegetation Classification (NVC; Rodwell, 1991). This type of woodland community is diverse and variable in both the ground flora and tree species composition and structure. Generally, the presence of *Fraxinus excelsior*, *Acer campestre* and *Corylus avellana*, sometimes dominant, especially in historical coppices (particularly ash and hazel in Wytham Woods), indicates this woodland type. *Quercus robur* is the other common species found in these woodlands, while *Acer pseudoplatanus* (sycamore) is rarer in the south-east of the country. However, in the SIGEO Wytham Woods plot A. *pseudoplatanus* is the most frequent species, a reflection of its rapid colonisation of open or disturbed areas, maybe due to the availability of local seed sources from planted stock.

The other trees in the Wytham W8 community are uncommon or infrequent throughout the plot, some only present as rare scattered individuals (e.g., *Carpinus betulus*, *Ilex aquifolium*), others with patchy local abundance (e.g., *Betula* spp., *Prunus spinosa*). Birch is widely found as an infrequent member of the community, generally not coppiced, as indeed is the case in Wytham Woods. Two rarely occurring species, *Tilia cordata* and *Carpinus betula* are not restricted to this type of woodland, though when they do occur it is as scattered individuals,

lime especially as relics of an earlier woodland cover. In Wytham the present lime trees are *Tilia x europaea*: *T. cordata* is found only in the pollen record (Hone *et al.*, 2001). On lighter base-rich soils *Fagus sylvatica* can compete with the principal trees of the community such that it may even drive the development of the community into beech-dominated high forest, however, in the plot this species is largely planted on the top of the hill where the soils are less heavy. *Crataegus monogyna* is a common associate of *Corylus avellana* in this type of woodland, and *Sambucus nigra* and *Prunus spinosa* are much less common but often found patchily here.

The ground flora of this woodland type is also variable, determined by soil, aspect and management history, but is characterised by dominant *Mercurialis perennis* (dog's mercury) and changeable combinations of *Endymion non-scripta* (bluebell), *Circaea lutetiana*, *Geum urbanum*, *Arum maculatum* and *Viola riviniana/reichenbachiana* (Figure 1.2). *Rubus fruticosus* and bryophytes are common features of the field layer, in addition to the sedge *Carex sylvatica* and the grasses *Poa trivialis* and *Brachypodium sylvatica*. Ferns are also sparsely present in Wytham. There are several sub-communities associated with W8 woodland – in the plot there are indications of gradation between types (e.g., *Allium ursinum* sub-community and *Mercurialis-Endymion* community).

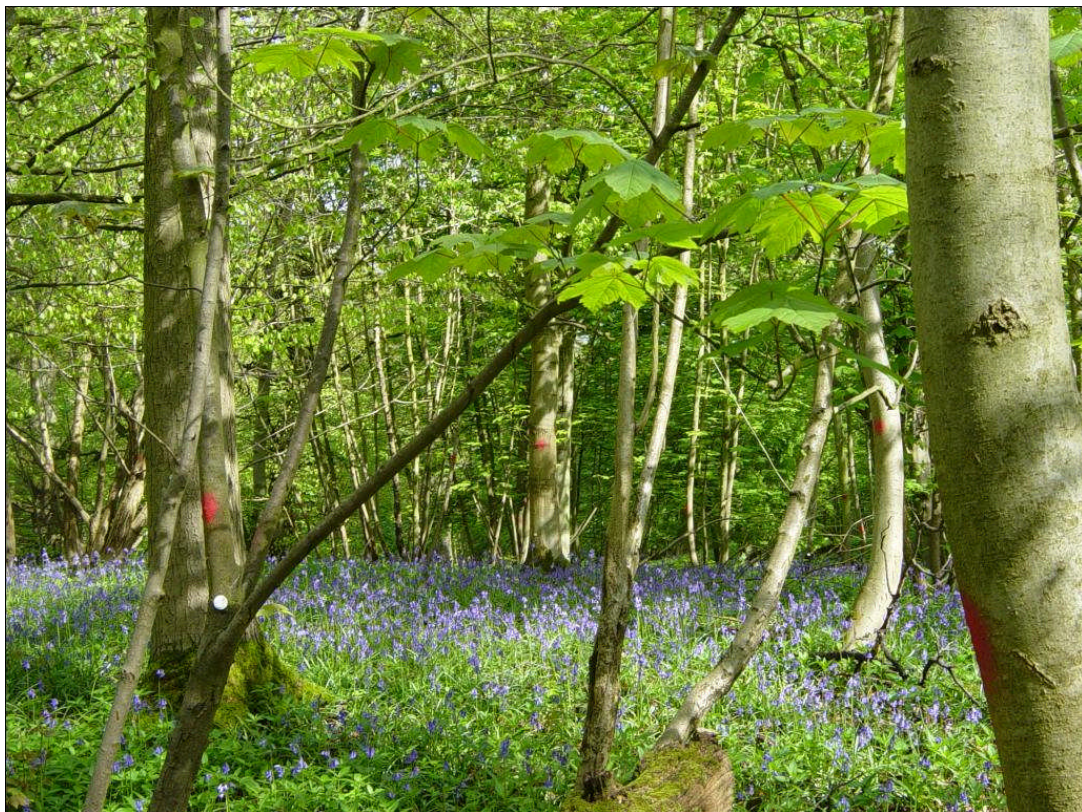


Figure 1.2: *Mercurialis perennis* and *Endymion non-scripta* community

The latest SSSI notification (Natural England) describes Wytham Woods and lists, in addition to the common and frequent species, rarer and more localised field layer species. For example, *Paris quadrifolia* and *Viola reichenbachiana* are both ancient woodland indicators and are found on the clay-rich parts of the plot. Other rare species recorded here include *Orchis mascula* (Figure 1.3).



Figure 1.3: *Orchis mascula* – early purple orchid.

Wytham climate

In comparison to most of Europe, the climate of the UK is maritime and mild, with snow rare in winter and summer temperatures rarely above 30 °C. Rainfall is evenly distributed throughout the year while January is the coldest month and July the warmest. This region is buffered from Atlantic depressions by the west of the country and thus the climate is relatively calm. The Centre for Ecology and Hydrology (CEH) has been recording meteorological data at Wytham since 1993 as part of the UK Environmental Change Network programme (ECN) (see also Morecroft *et al.*, 1998): the mean annual temperature is 10°C and the mean annual rainfall is 726 mm, a little less than the city of Oxford nearby, and mean annual radiation is 118 W/m² (Figure 1.4).

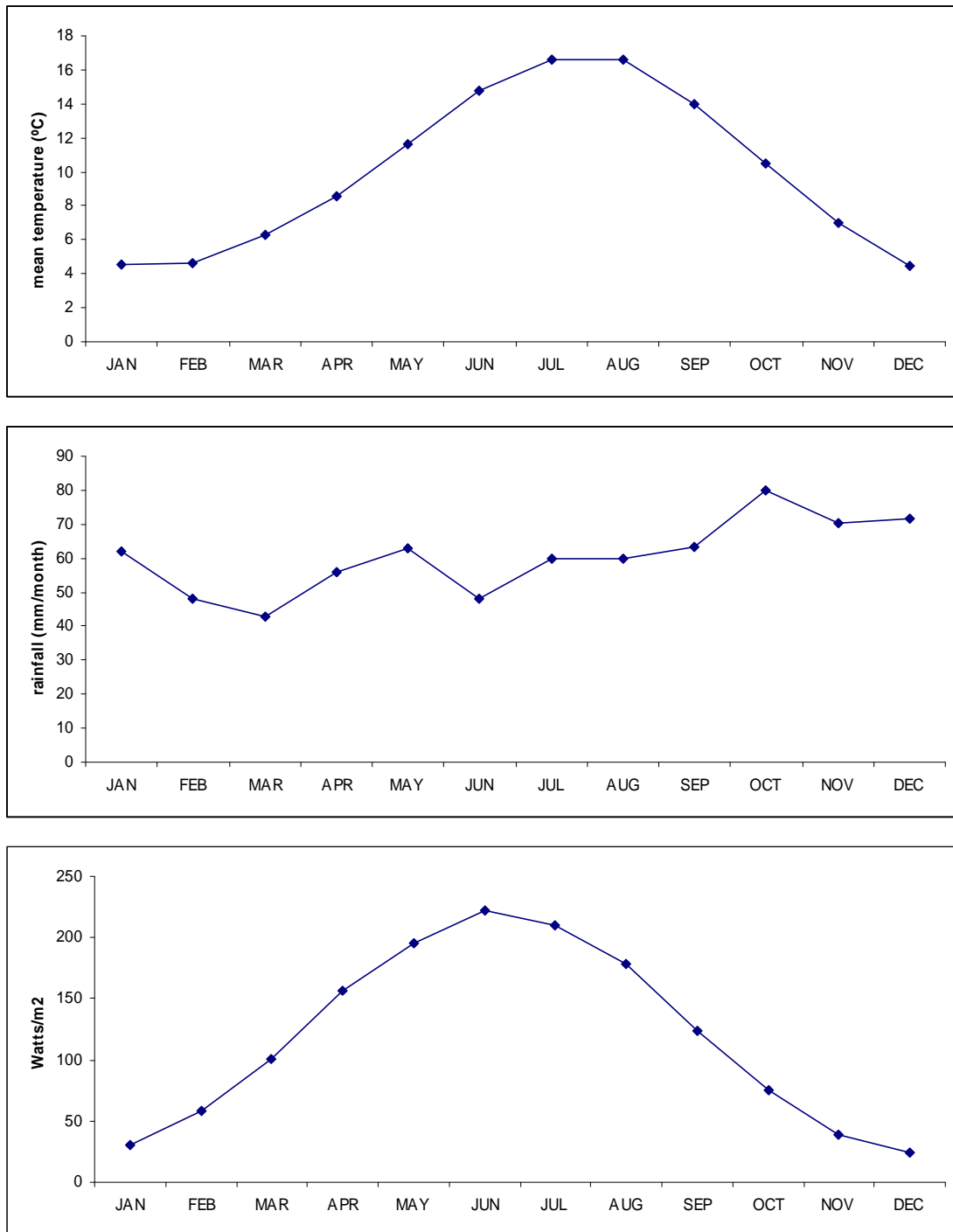


Figure 1.4: Annual cycles of temperature, rainfall and solar radiation, from ECN monthly mean data, 1993-2008/9.

Topography

The plot lies on the north facing slope of Wytham hill, along a relatively continuous gradient. The mean slope gradient for the plot is -0.09 m/m^{-1} , from south to north. Within this broad range the slope is broken down into a series of slopes and troughs, indicated in the four long transect profiles below (Figure 1.5). Despite this, the gradient very rarely rises above 1 in 3.

The only major anomaly in this topographic pattern is a narrow strip along the western edge of the plot in the south-west corner, where the slope falls away sharply.

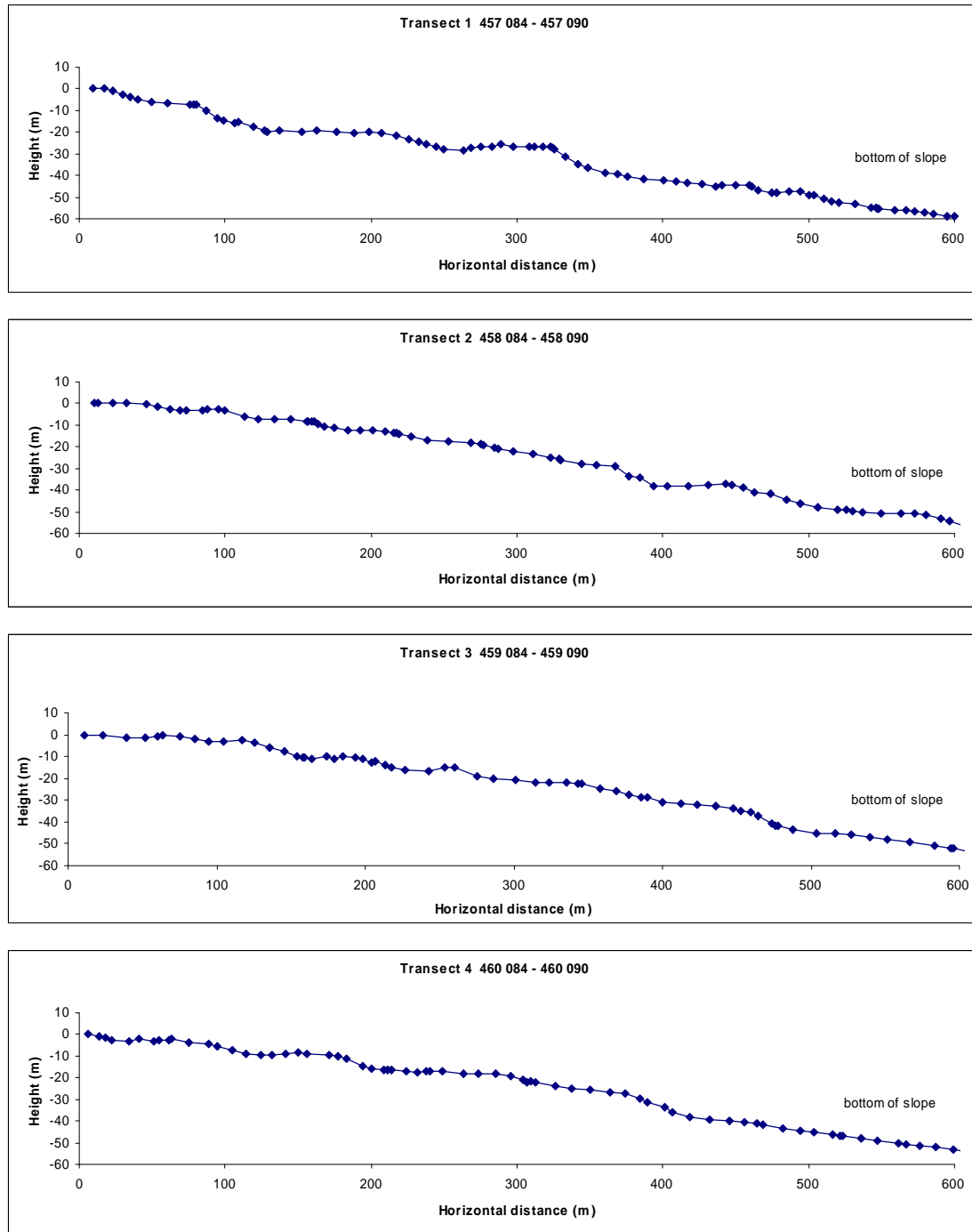


Figure 1.5: Line transect profiles of the plot along the north-south axis.

GPS and LIDAR data indicate an overall height range of 163m -103m from the south edge of the plot to the north, and closely agree with the line transect measurements. These data also suggests a small height drop (-3 m) from west to east at the southern end of the plot, which has become a height increase (+7m) by the northern end (Figure 1.6).

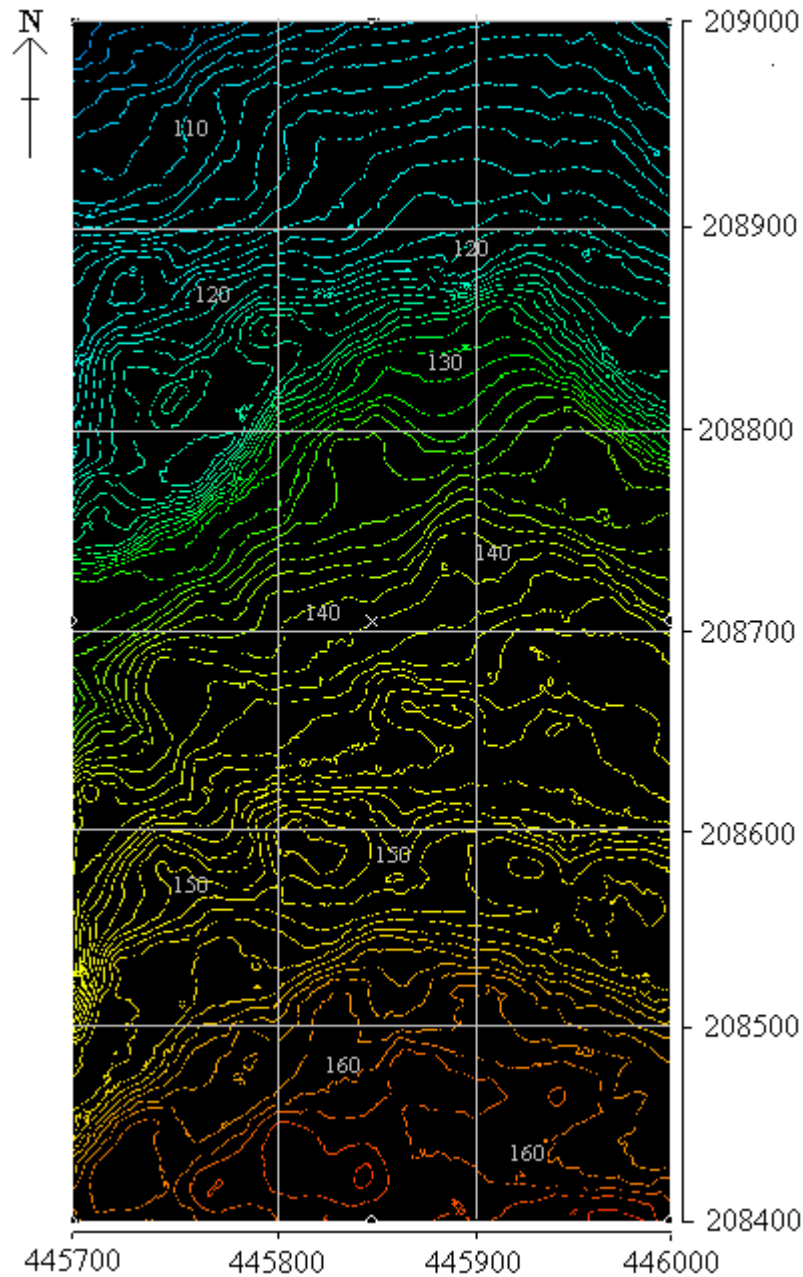


Figure 1.6: Plot topography map derived from aerial LIDAR (ground height) data for Wytham Woods. Contours are at 1m intervals, 163m is the highest (dark red) contour and 104m is the lowest (pale blue). Data from Ross Hill, CEH.

There is a 100 m x 100 m grid laid out in Wytham which was used to mark the boundaries of the 18 ha plot. However, measurements on the ground made during the marking out of the 1 ha plots indicated that these marker posts are not all exactly 100 m apart in a straight line east-west (Figure 1.7).

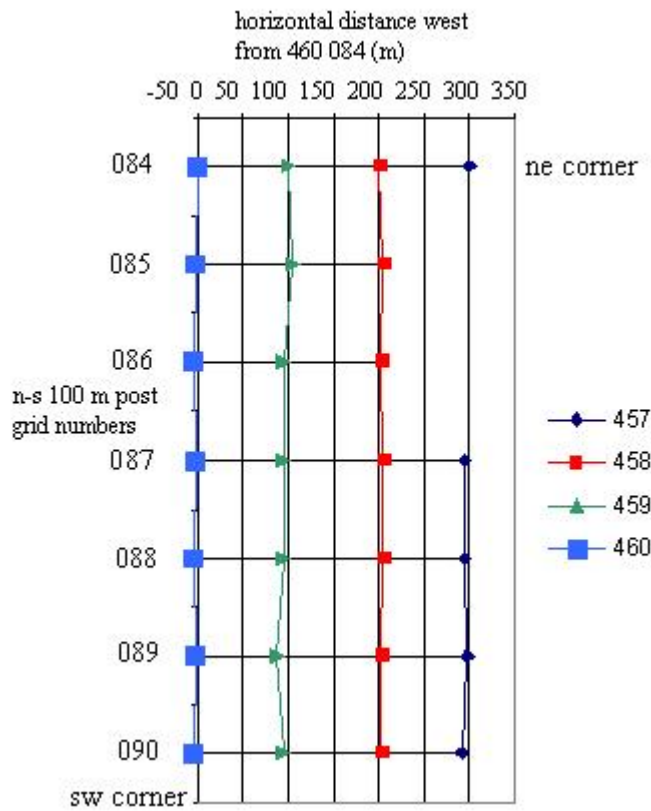


Figure 1.7: 100 m marker post location error. The coloured lines are the 600 m long north-south gridlines; the solid shapes represent the intersects with the 300 m east-west gridlines in the plot.

Current Wytham research

The large scale plot includes an intensive carbon cycle study plot of 1 ha, which was previously established in 2005. The aim was to measure and quantify tree and soil carbon processes. These include:

- soil respiration; total soil respiration measurements at fixed respiration collars began in the first plot in April 2006. In 2008 mesh bags were installed to partition soil respiration into root, mycorrhizal, and soil organic matter components.
- aboveground productivity; dendrometer bands are used to determine tree productivity - this method allows monthly changes in stem diameter to be detected, enabling the study of growth patterns over seasons and between species.
- tree stem respiration; respiration collars were fitted to a sample of ash and sycamore trees in the first plot and monthly stem respiration measurements were taken throughout the 2008 growing season.

- tree leaf production; canopy development and decline is recorded using the optical LAI-2000 method. Total leaf production, and each species' contribution to the canopy, is determined using litter traps.

Soil respiration and dendrometer band measurements are currently continued by Earthwatch-HSBC volunteers.

This plot also now contains an eddy covariance flux tower, installed in 2007 by CEH (funded by the Natural Environment Research Council, NERC), which provides an estimate of total ecosystem CO₂ uptake and release. Although not part of the Smithsonian/HSBC funded project, Chapter 9, which describes the flux data analysis, is included as an interesting counterpoint to the plot measurements.

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2 Tree census

Establishment of the long term monitoring plot

All the plots in the CTFS network, which range in size from 2ha in Bukit Timah in Singapore to 52ha at Lambir in Malaysia, have a common plot structure and scientific methodology, which have also been applied in Wytham. After selection of the 18 ha block, each hectare was marked out and within each hectare 25 20 m x 20 m subplots were delimited. Each stem with a diameter-at-breast-height (dbh), (usually 1.3 m), of 1 cm or greater was included in the census. Each stem was tagged with a unique tag number, identified to species where possible, marked at the point of measurement, and mapped using the east-west and north-south boundaries of the subplot as axes. Where a stem was part of a group, or multistem, rather than an individual tree, it was tagged and measured if it was 5 cm or greater (dbh), and allocated 'main' or 'secondary' stem status. The number of stems between 1 cm and 5 cm in each multistem was recorded but not measured. Dead stems (if still solidly standing) were included in the census as 'D', leaning or horizontal stems were included as 'L' and 'Q' was allocated to stems with a missing or broken trunk above 1.3 m. (See CTFS protocol documents for further detail). This work was carried out between August and October 2008. The data were recorded and have been uploaded to the CTFS server.

23 tree species were recorded in the plot:

<u>Latin name</u>	<u>Common name</u>	<u>code</u>	<u>no. individuals</u>
<i>Acer campestre</i>	Field maple	ACERCA	125
<i>Acer pseudoplatanus</i>	Sycamore	ACERPS	7716
<i>Betula</i> spp.	Birch	BETUSP	85
<i>Carpinus betulus</i>	European/Common hornbeam	CARPBE	1
<i>Castanea sativa</i>	Sweet chestnut	CASTSA	1
<i>Corylus avellana</i>	Common hazel	CORYAV	861
<i>Crataegus monogyna</i>	Common hawthorn	CRATMO	1308
<i>Euonymus europaeus</i>	European/Common spindle	EUONEU	29
<i>Fagus sylvatica</i>	European/Common beech	FAGUSY	195
<i>Frangula alnus</i>	Alder buckthorn	FRANAL	4
<i>Fraxinus excelsior</i>	European/Common ash	FRAXEX	5346
<i>Ilex aquifolium</i>	European/Common holly	ILEXAQ	5
<i>Larix decidua</i>	European larch	LARIDE	99
<i>Picea abies</i>	Norway spruce	PICEAB	11
<i>Pinus sylvestris</i>	Scots pine	PINUSY	1
<i>Prunus avium</i>	Wild cherry	PRUNAV	3
<i>Prunus spinosa</i>	Blackthorn	PRUNSP	29
<i>Pseudotsuga menziesii</i>	Douglas fir	PSEUME	1
<i>Quercus robur</i>	Pedunculate/English oak	QUERRO	381
<i>Salix</i> spp.	Willow	SALISP	31
<i>Sambucus nigra</i>	Elder	SAMBNI	77
<i>Taxus baccata</i>	English yew	TAXUBA	1
<i>Tilia x europaea</i>	Common lime	TILIEU	3

In total, 20,308 stems were recorded; 16313 individual trees (Figure 3).

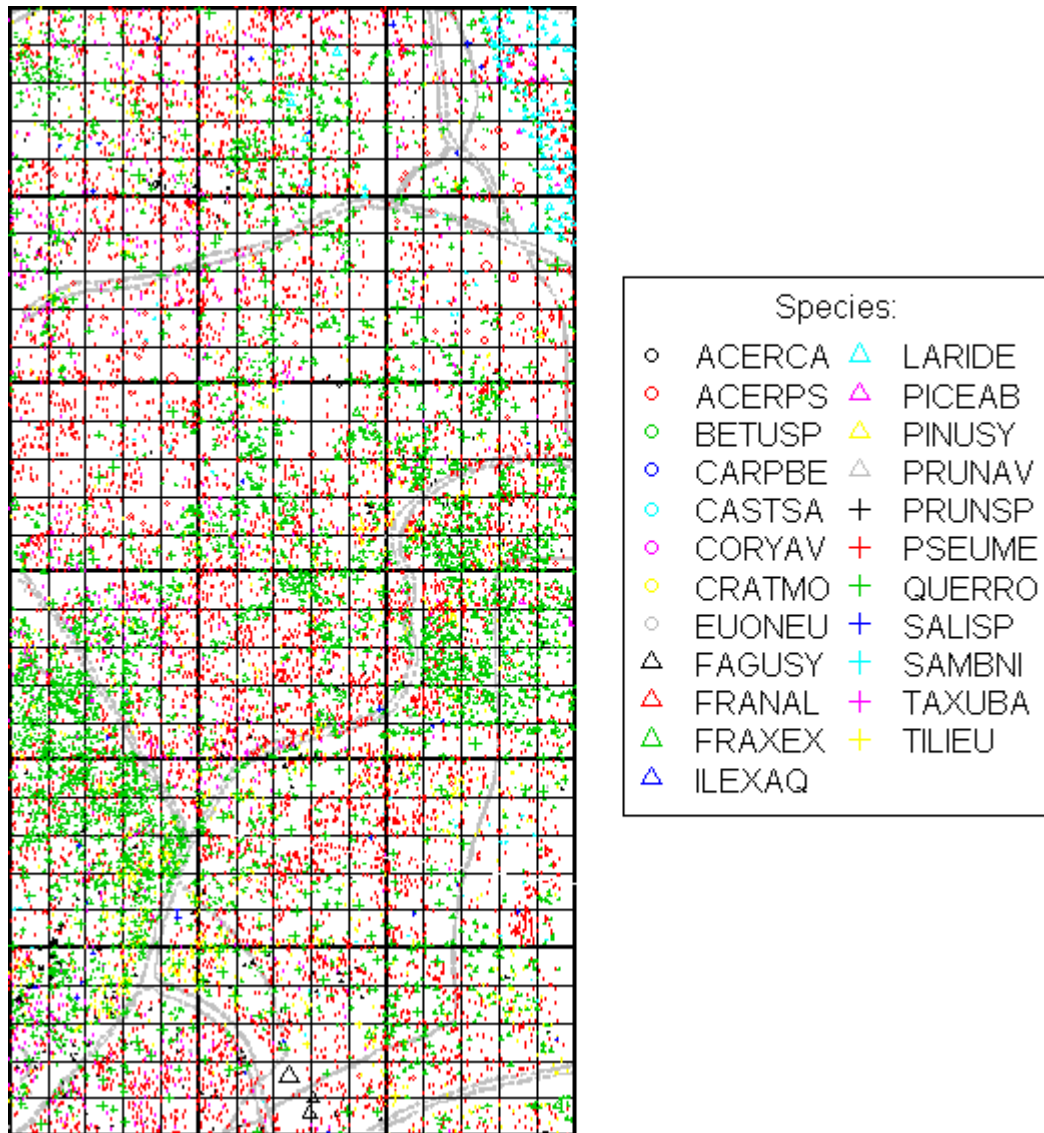


Figure 3: Distribution of the tree species throughout the 18 ha plot.

Tree census data

A. pseudoplatanus made up over half of the stems in the plot as a whole, with nearly 600 stems per hectare. *F. excelsior* was the next biggest contributor, with over a quarter of all stems, about 300 stems per hectare; *Corylus avellana* and *Crataegus monogyna* each contributed between 5% and 10% of all stems, around 100 (*Corylus avellana*) and 80 (*Crataegus monogyna*) per hectare (Table 2.1, Figures 2.4 & 2.5).

Table 2.1: Stem numbers and basal area per hectare for each species.

	Stems per hectare	Basal area (m ² ha ⁻¹)
<i>Acer campestre</i>	7.72	0.2197
<i>Acer pseudoplatanus</i>	582.72	16.86
<i>Betula</i> spp.	4.94	0.2171
<i>Carpinus betulus</i>	0.06	0.0015
<i>Castanea sativa</i>	0.06	0.0011
<i>Corylus avellana</i>	100.28	0.4422
<i>Crataegus monogyna</i>	77.17	0.3495
<i>Euonymus europaeus</i>	1.61	0.0054
<i>Fagus sylvatica</i>	11.11	0.4409
<i>Frangula alnus</i>	0.22	0.0019
<i>Fraxinus excelsior</i>	304.72	6.6874
<i>Ilex aquifolium</i>	0.33	0.0025
<i>Larix decidua</i>	5.50	1.0434
<i>Picea abies</i>	0.83	0.0901
<i>Pinus sylvestris</i>	0.06	0.0144
<i>Prunus avium</i>	0.17	0.0023
<i>Prunus spinosa</i>	1.61	0.0051
<i>Pseudotsuga menziesii</i>	0.06	0.0085
<i>Quercus robur</i>	21.33	6.7063
<i>Salix</i> spp.	1.83	0.0985
<i>Sambucus nigra</i>	5.28	0.0424
<i>Taxus baccata</i>	0.06	0.0002
<i>Tilia x europaea</i>	0.56	0.0617
Total	1128.2	33.3

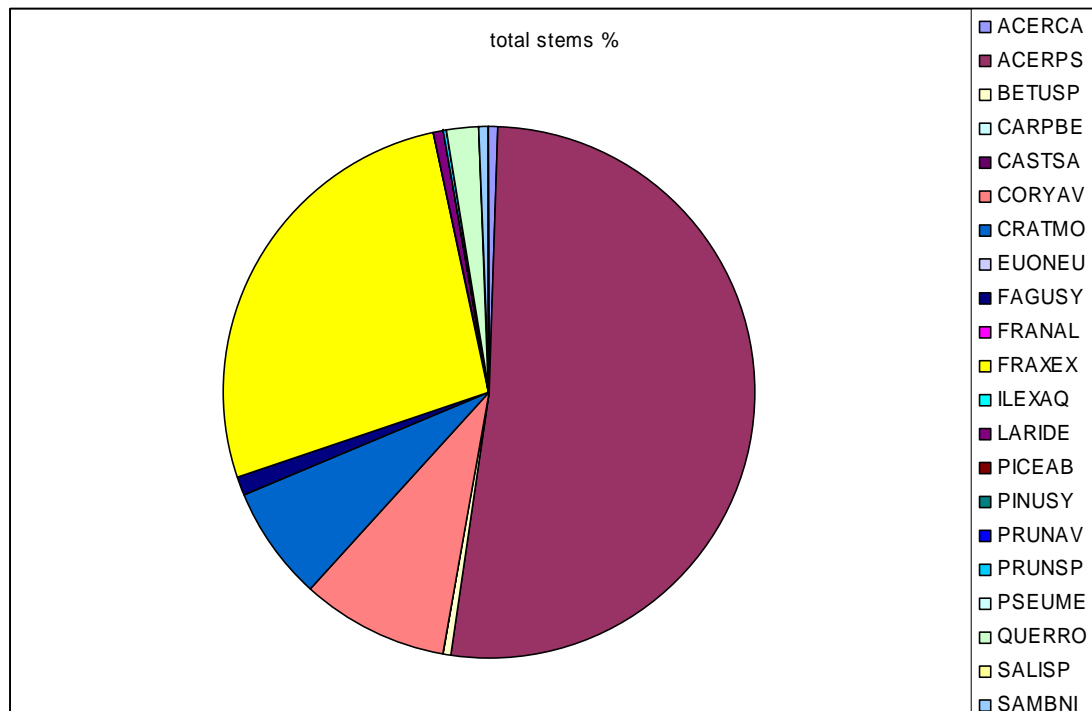


Figure 2.4: Total stem numbers by species.

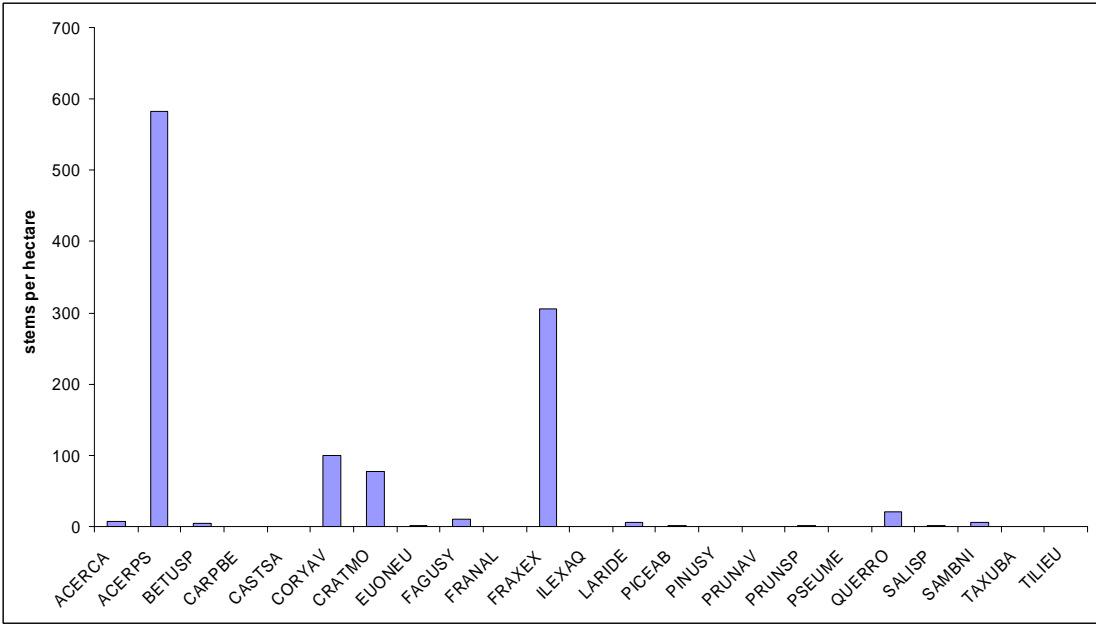


Figure 2.5: Stems per hectare by species.

Basal area was similarly dominated by *A. pseudoplatanus*, which again accounted for half of the total for all trees, nearly $17 \text{ m}^2 \text{ ha}^{-1}$, while *Q. robur* and *Fraxinus excelsior* were the next biggest contributors with nearly $7 \text{ m}^2 \text{ ha}^{-1}$ each. In total, these three species contribute about 90% of plot basal area, on average. *Corylus avellana* and *Crataegus monogyna*, though important in terms of stem numbers, contributed less than *Fagus sylvatica* and *L. decidua* by basal area (Figures 2.6 & 2.7). *Q. robur* contributes disproportionately to basal area as a result of the large mean size of the individuals.

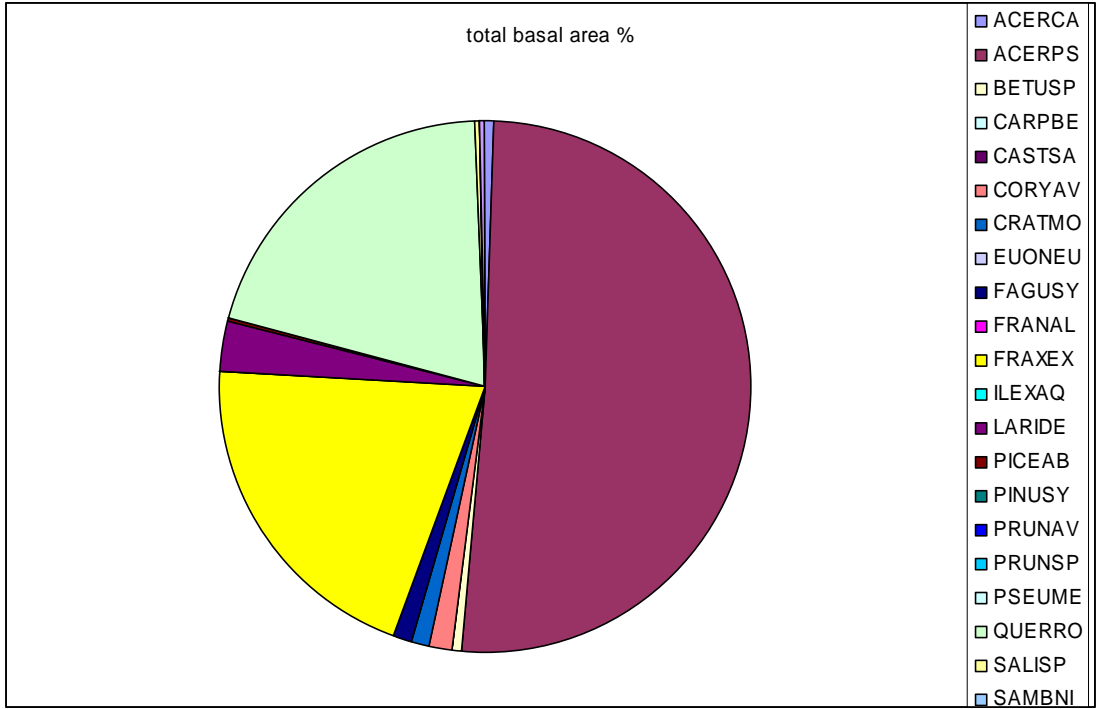


Figure 2.6: Total basal area by species.

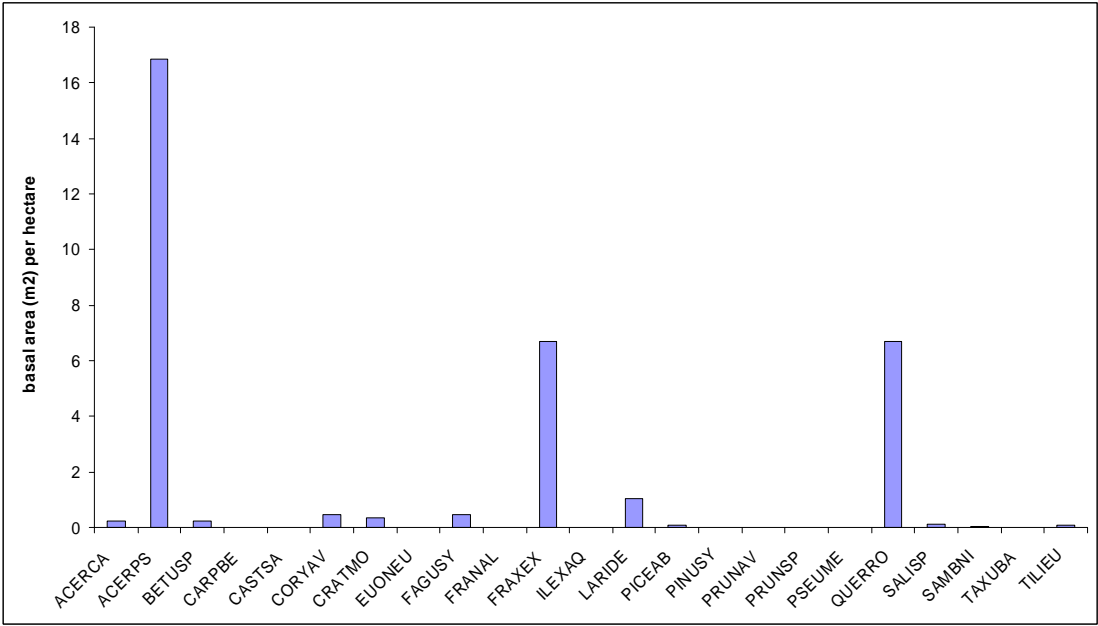


Figure 2.7: Basal area per hectare by species.

Tree distributions

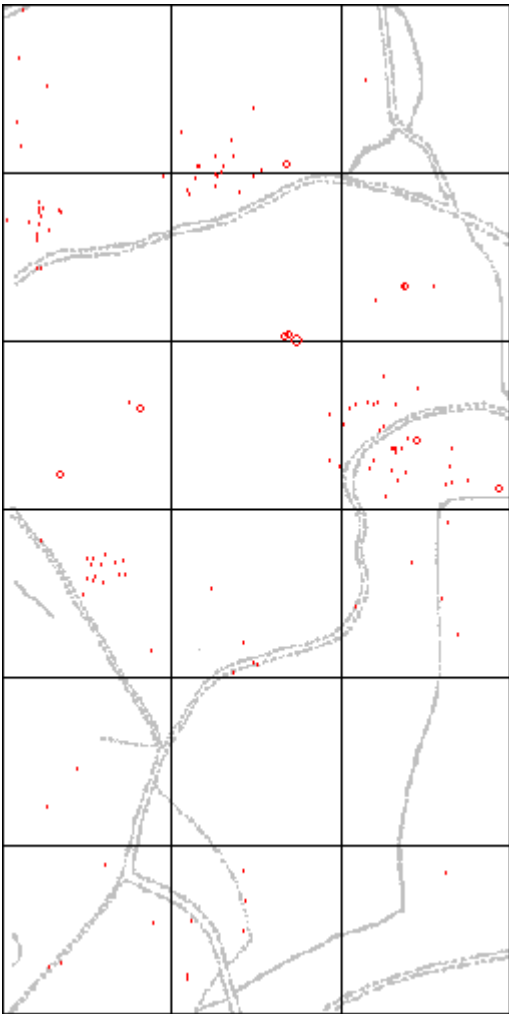
Species	General distribution	Notes/interpretation
<i>Acer campestre</i>	A few loose groups, less frequent in the upper part of the plot	
<i>Acer pseudoplatanus</i>	The most numerous species in the plot, widespread, the largest individuals are more frequent in the lower part of the plot	Highly successful invader of semi-natural ancient woodland areas in the plot., also previously used as coppice wood (until about 1920), planted early 19C
<i>Betula</i> spp.	A couple of groups at the top of the slope, very few scattered individuals elsewhere	Generally found in this type of woodland
<i>Carpinus betulus</i>	One individual at the top of the slope	A rare associate of this woodland type
<i>Castanea sativa</i>	One individual at the top of the slope	An uncommon associate of this woodland type
<i>Corylus avellana</i>	Widespread except for the south east of the plot, denser grouping in the upper half of the plot	Common species of this woodland type, also used for coppice wood until approx. 1920
<i>Crataegus monogyna</i>	Widespread with low density in the lower mid-plot, denser grouping in the south west corner	
<i>Euonymus europaeus</i>	A few scattered individuals, slightly more common in the upper half of the plot	
<i>Fagus sylvatica</i>	Increasing in size and frequency with proximity to the southern edge and sw corner, not present in the north of the plot	Largest (oldest) individuals along southern margins of plot – previously planted and managed
<i>Frangula alnus</i>	A few scattered individuals, more in the south of the plot.	
<i>Fraxinus excelsior</i>	Frequent in most parts of the plot, with two dense stands in the mid-to-upper part	No apparent pattern to stem size distribution
<i>Ilex aquifolium</i>	Uncommon, few individuals	A rare associate of this woodland type.
<i>Larix decidua</i>	Grouped mainly in the north eastern corner	Edge of historical plantation
<i>Picea abies</i>	Grouped mainly in the north eastern corner	Edge of historical plantation
<i>Pinus sylvestris</i>	One individual in the north east.	Edge of historical plantation
<i>Prunus avium</i>	Uncommon, few individuals	A rare associate of this woodland type
<i>Prunus spinosa</i>	Grouped mainly in the north west corner	Thickets of this species are found throughout the ancient woodland in Wytham
<i>Pseudotsuga menziesii</i>	One individual in the eastern margins	Edge of historical plantation
<i>Quercus robur</i>	Widespread and common except in the south east corner, slightly more populous in the upper part of the plot	Very few juveniles, declining in dominance, previously managed
<i>Salix</i> spp.	Infrequent, a few individuals in the northern edge, mostly in the upper half of the plot	
<i>Sambucus nigra</i>	Quite widespread, loose groups and individuals.	
<i>Taxus baccata</i>	Very uncommon, one individual, structural parasite (Figure 2.8)	Accidental – bird dispersal
<i>Tilia x europaea</i>	Few individuals at southern edge	Planted in early 20th C



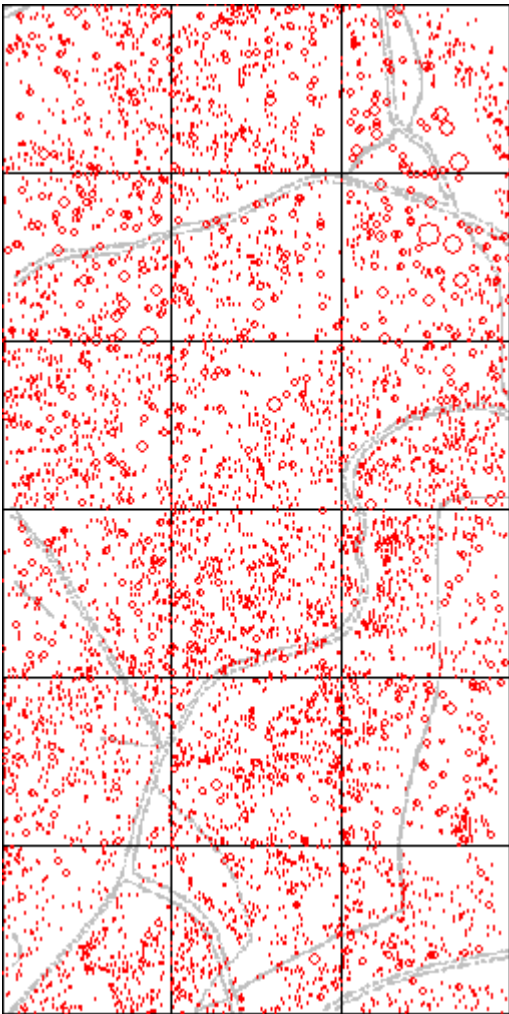
Figure 2.8: Structural parasite – *Taxus baccata* growing in an *A. pseudoplatanus*.

F. excelsior and *Q. robur* were previously the dominant species (canopy cover and basal area), currently *F. excelsior* and *A. pseudoplatanus* are co-dominant, probably partly as a result in the reduction in rabbit damage during the last half century (Kirby, 2009). Previously there were a lot more coppices (of *C. avellana* and perhaps other species); when the coppice layer was cut out to turn the wood into high forest the resultant gaps were mostly colonised by *A. pseudoplatanus*. Damage by deer has overtaken damage by rabbits and, combined with the cessation of coppicing, is probably responsible for the retardation of regeneration of smaller trees. There are indications that *F. excelsior* is outgrowing *A. pseudoplatanus* – it is growing faster and producing more seedlings (Morecroft *et al.*, 2008). This could be because *A. pseudoplatanus* tends not to become dominant under dense canopy (so does not do well under larger trees of the same species), or perhaps its drought sensitivity means it is less competitive than *F. excelsior* under drying climatic conditions.

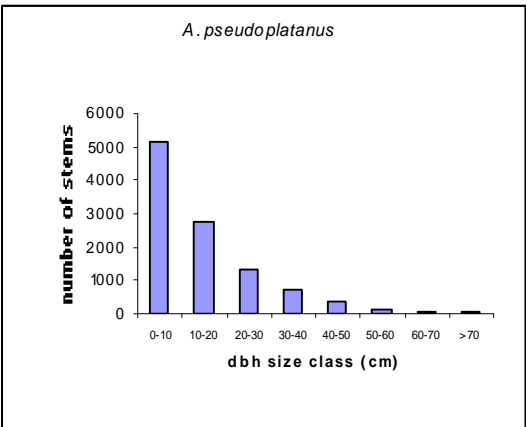
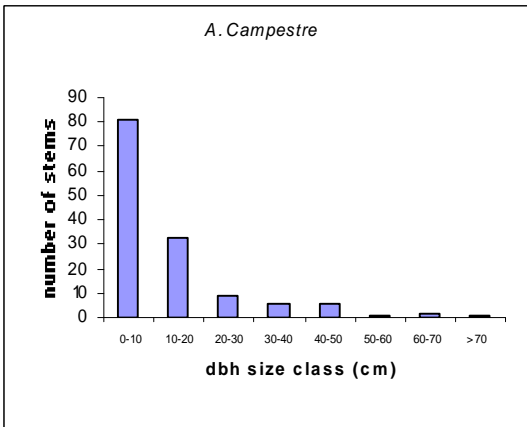
The following maps give the distribution for each species for the whole 18 ha plot. Species with more than ten stems are also shown by size class.

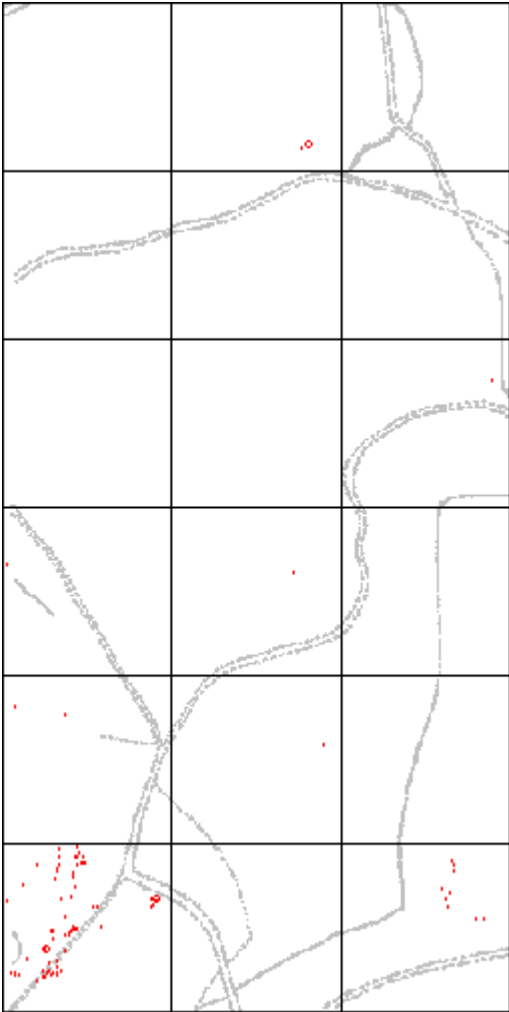


Acer campestre – largest stem 79.7 cm dbh

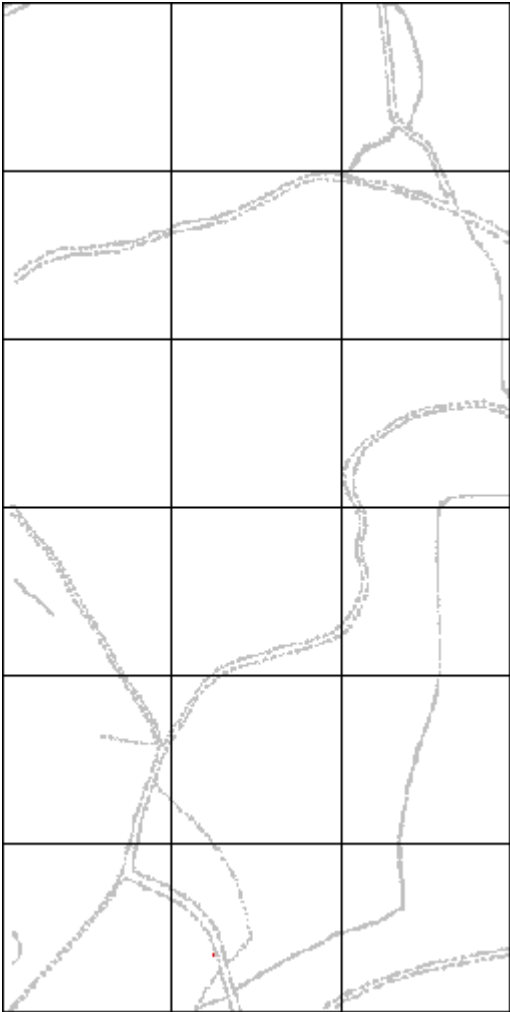


Acer pseudoplatanus – largest stem 149.45 cm dbh

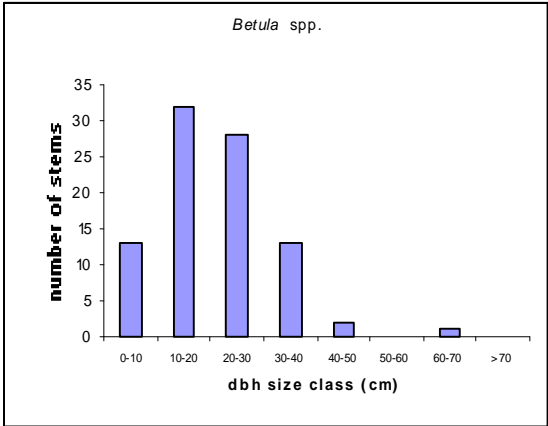


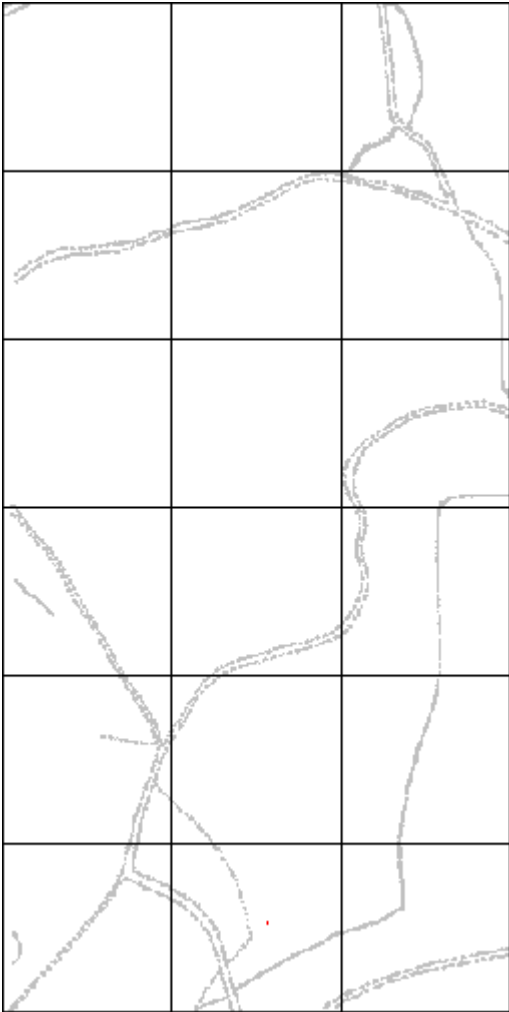


Betula spp. - largest stem 61 cm dbh

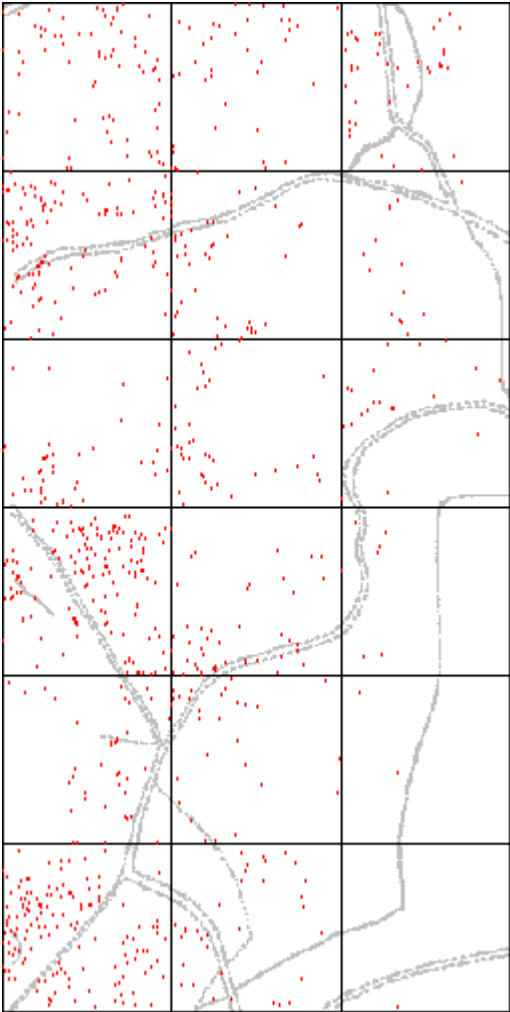


Carpinus betulus – 18.8 cm dbh

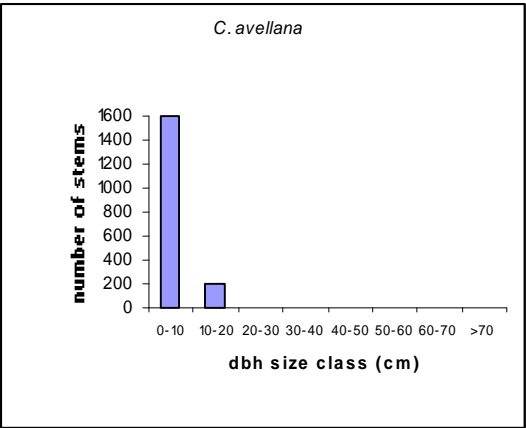


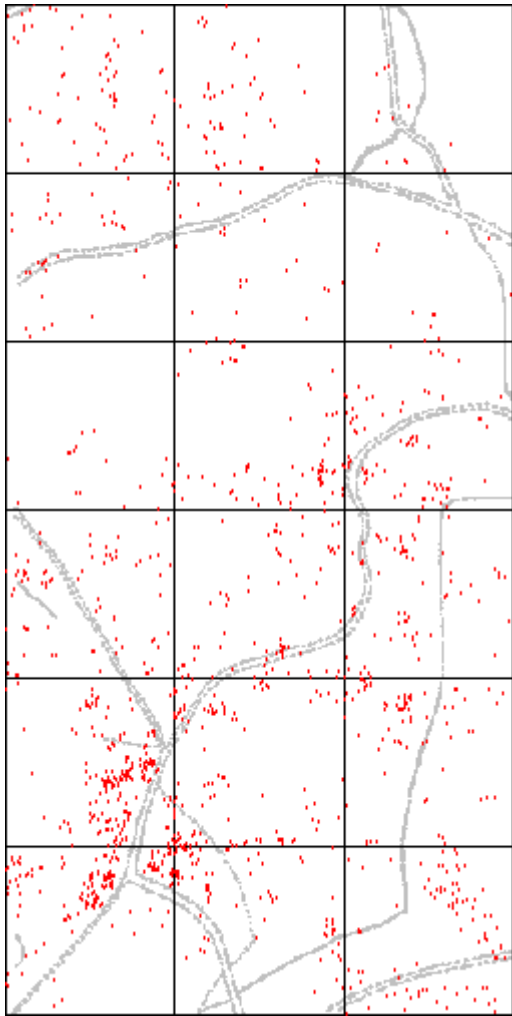


Castanea sativa – 15.7 cm dbh

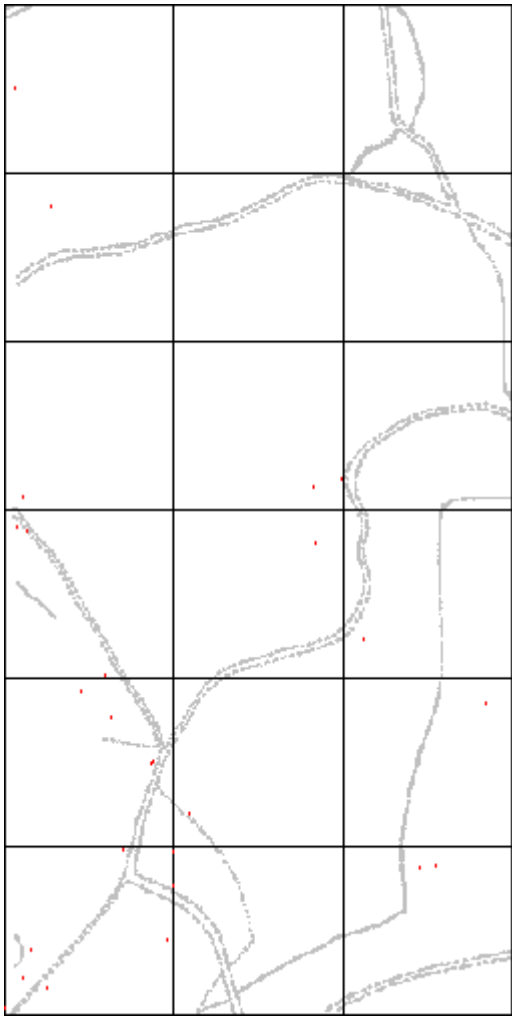


Corylus avellana – largest stem 30.2 cm dbh

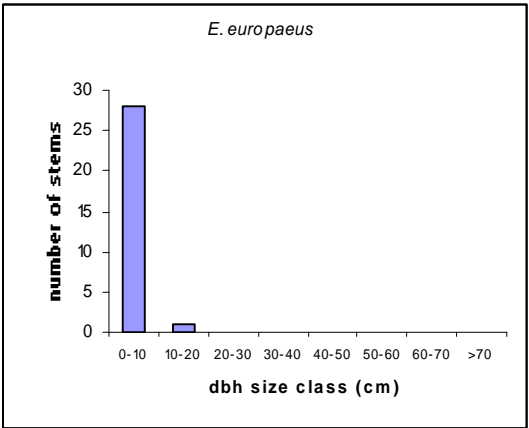
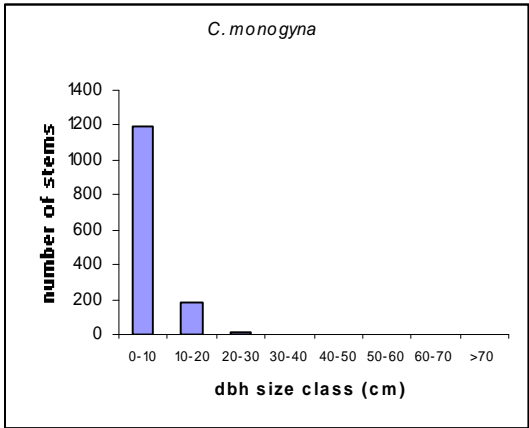


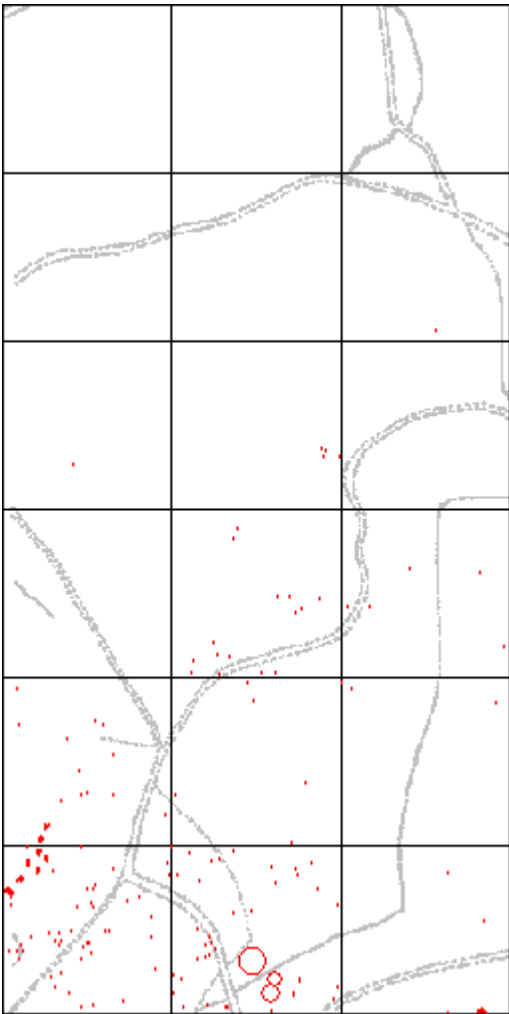


Crataegus monogyna –
largest stem 38.4 cm dbh

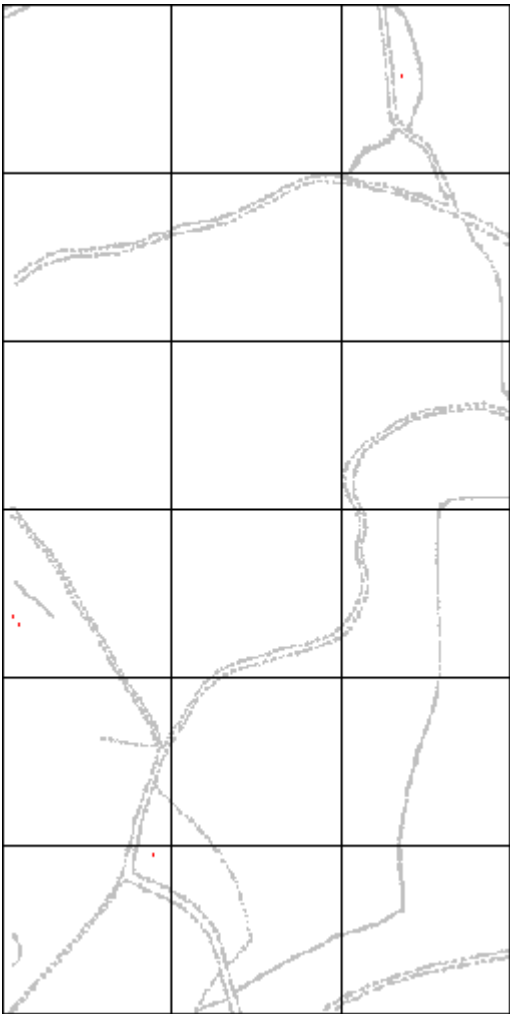


Euonymus europaeus –
largest stem 11.2 cm dbh

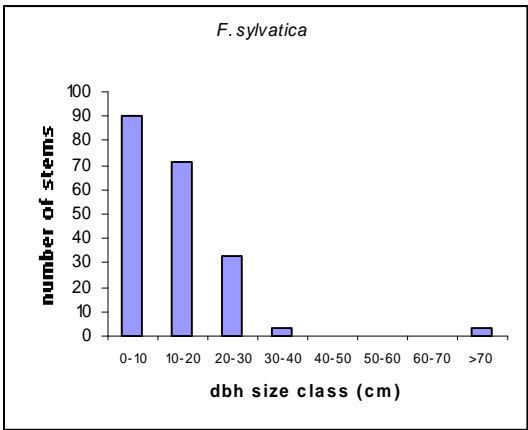


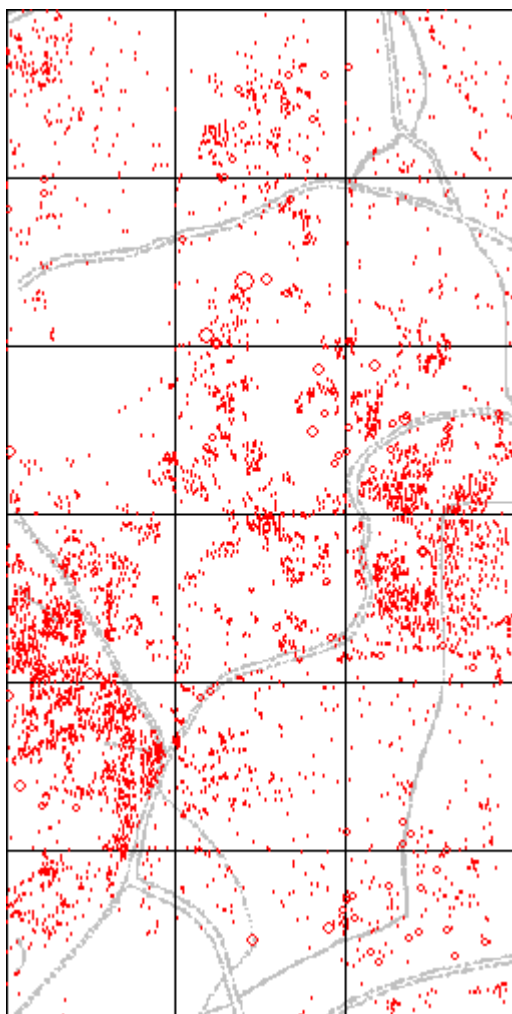


Fagus sylvatica – largest stem 182.5 cm dbh

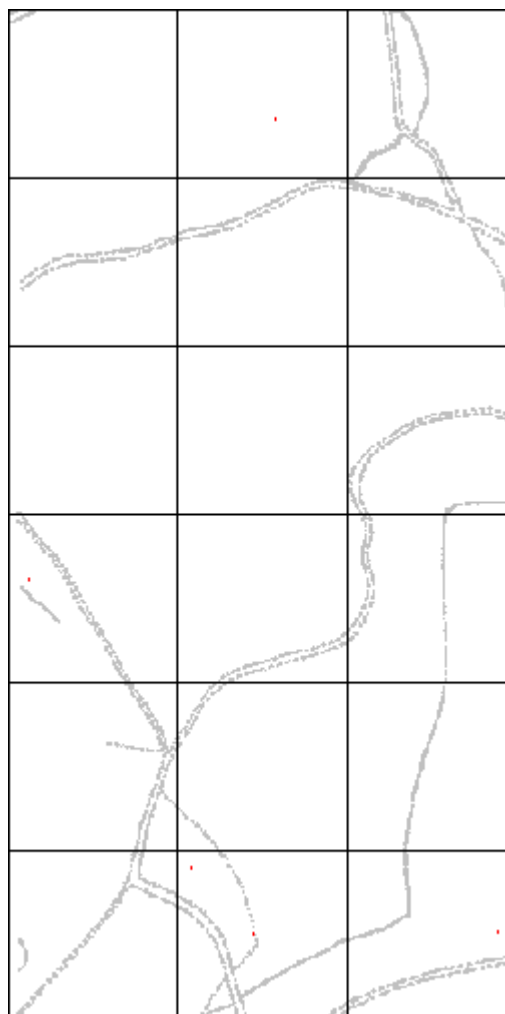


Frangula alnus – largest stem 18.3 cm dbh

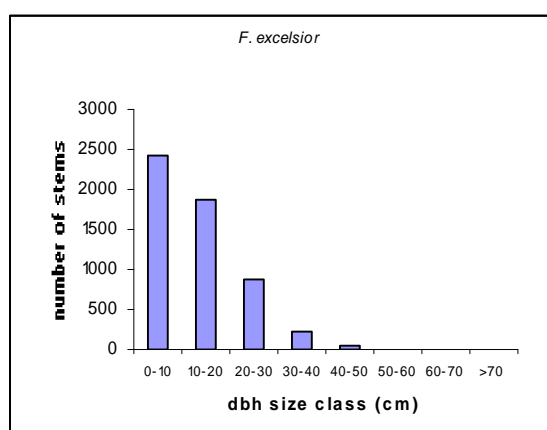


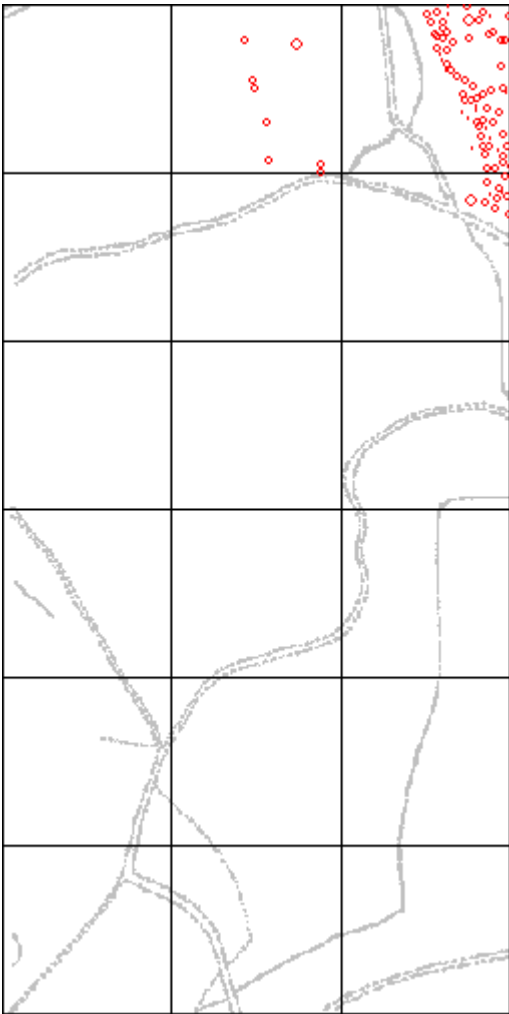


Fraxinus excelsior –
largest stem 124.2 cm dbh

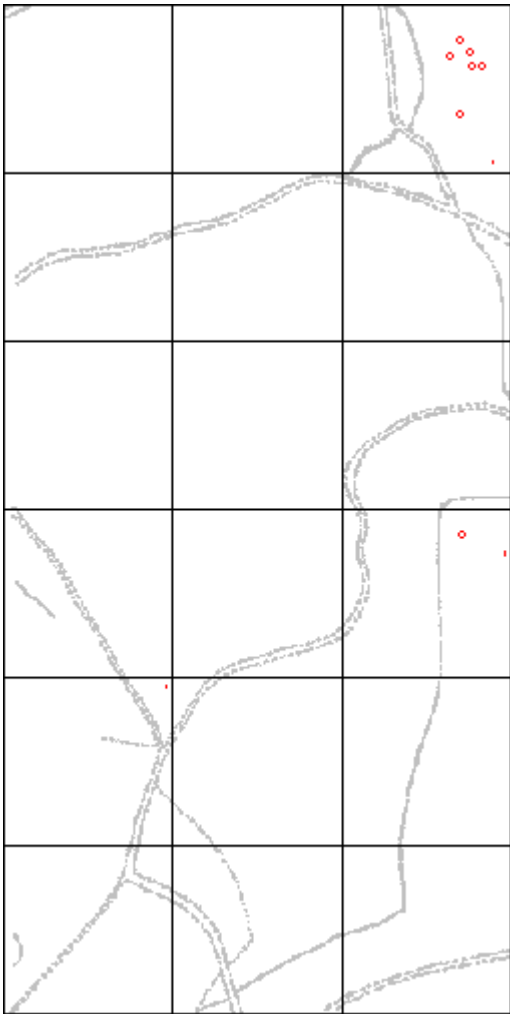


Ilex aquifolium – largest stem 14 cm dbh

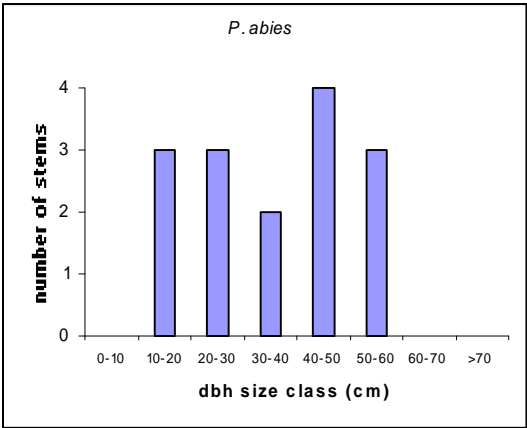
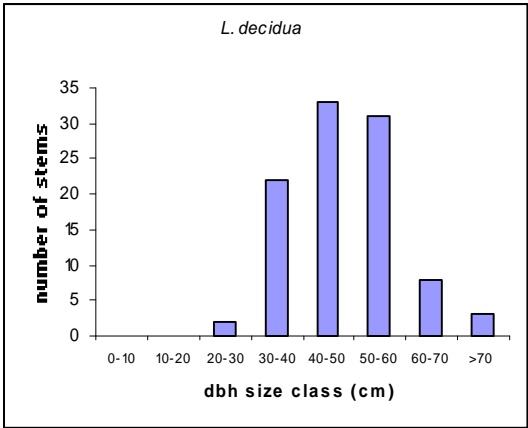


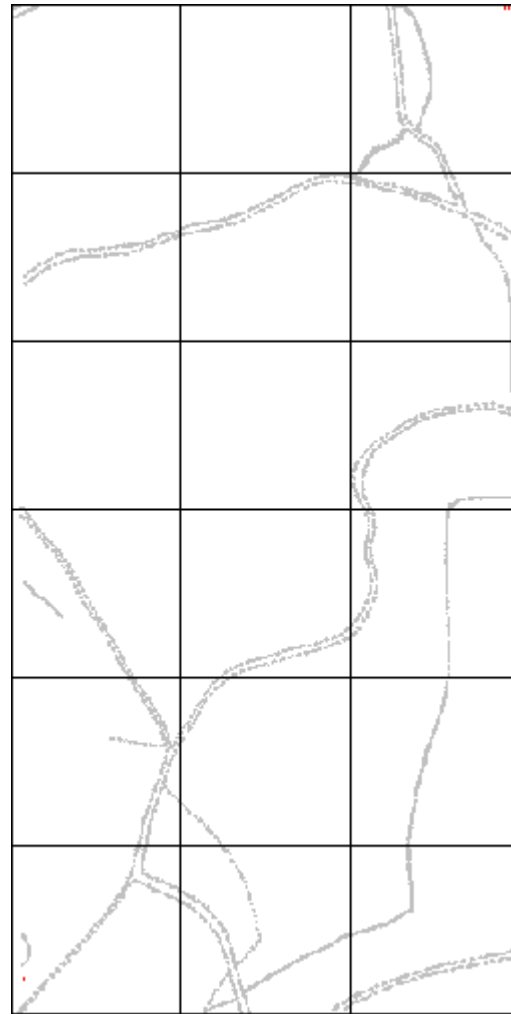
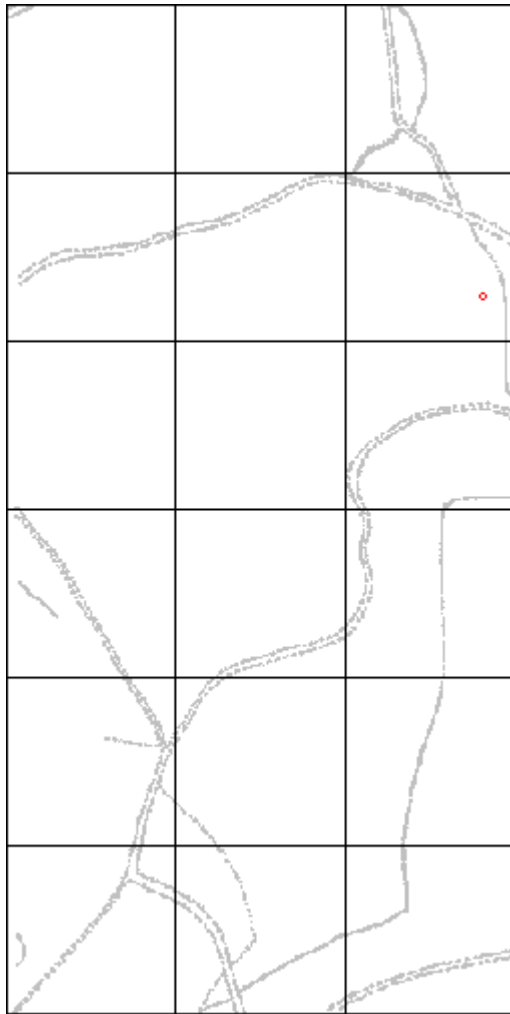


Larix decidua – largest stem 78.25 cm dbh

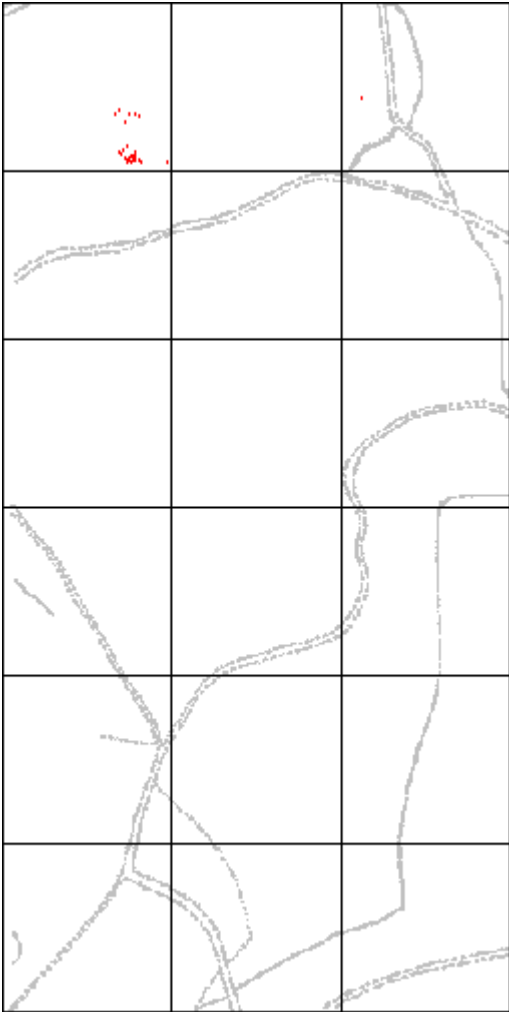


Picea abies – largest stem 54.9 cm dbh

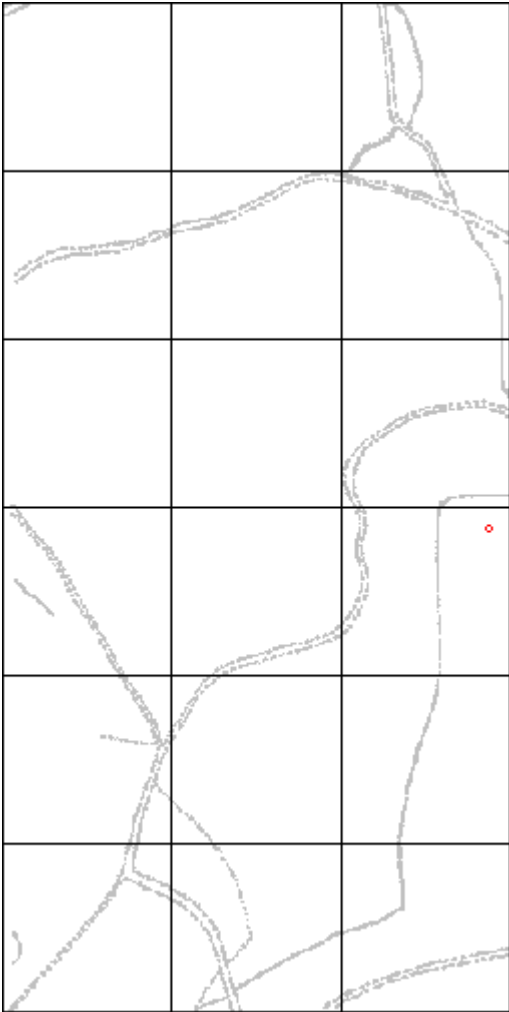




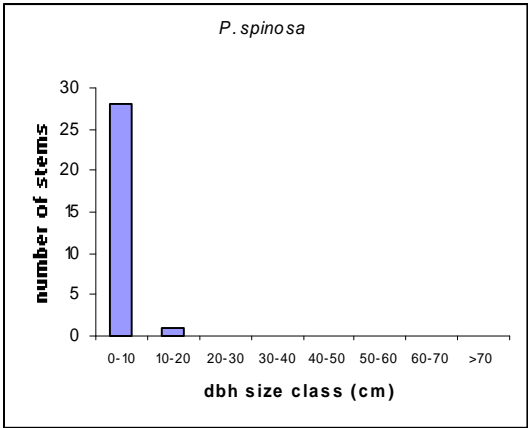
Pinus sylvestris – largest stem 57.5 cm dbh *Prunus avium* – largest stem 15.9 cm dbh

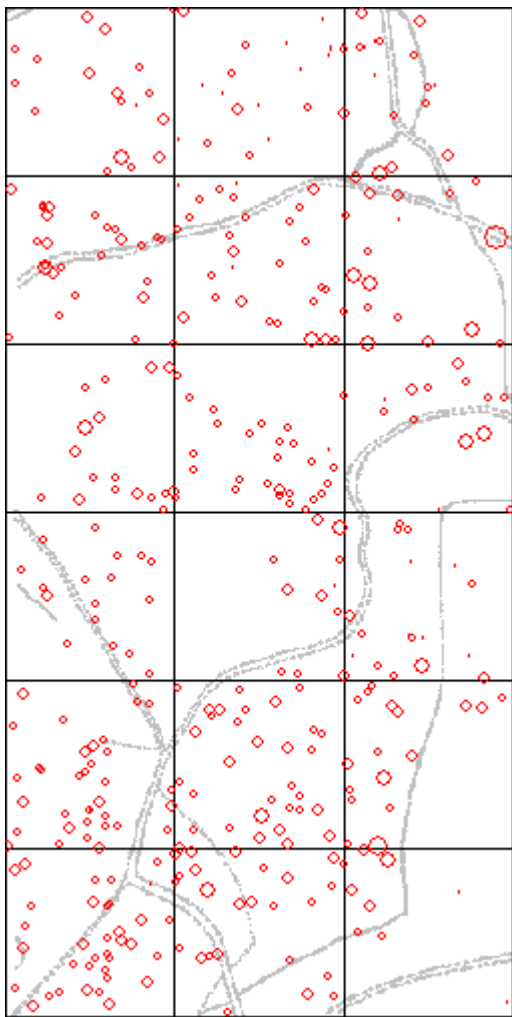


Prunus spinosa – largest stem 15.4 cm dbh

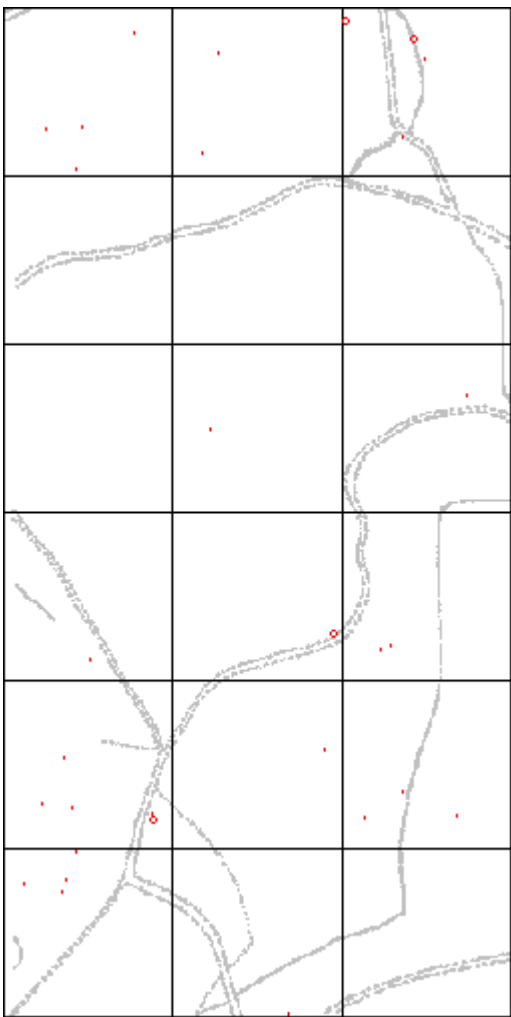


Pseudotsuga menziesii 44.2 cm dbh

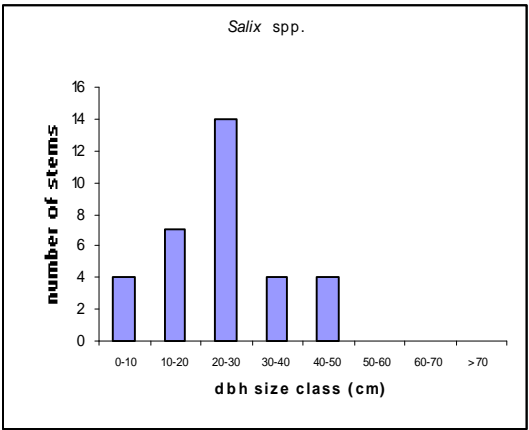
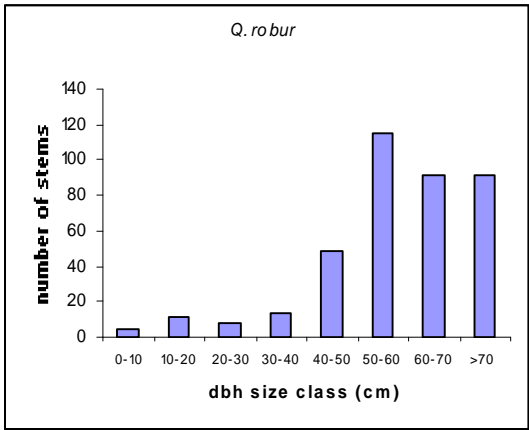


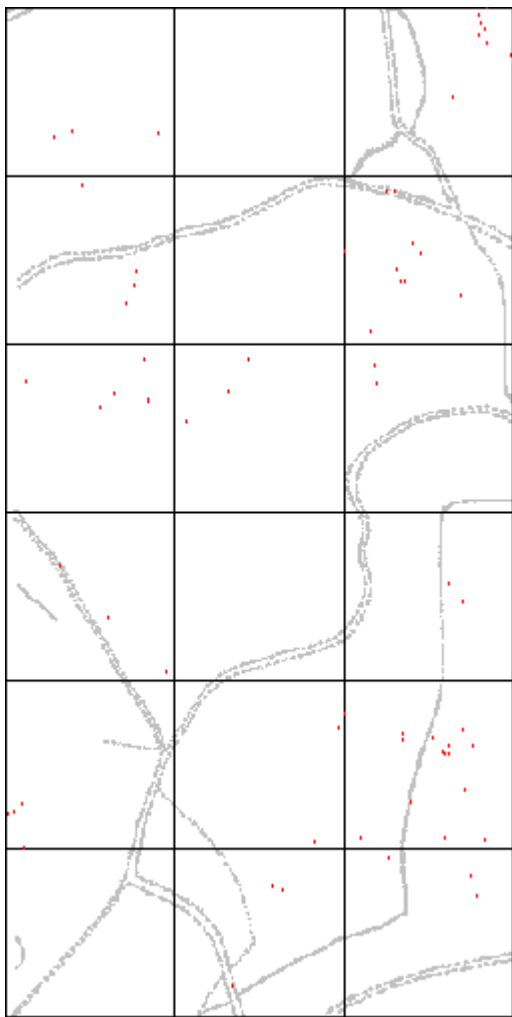


Quercus robur – largest stem 150.9 cm dbh

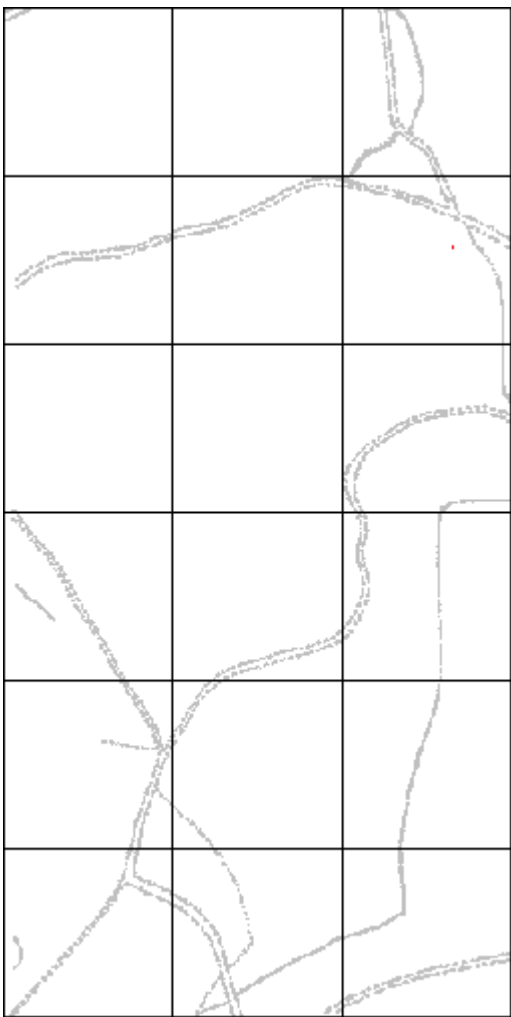


Salix spp. largest stem 47 cm dbh

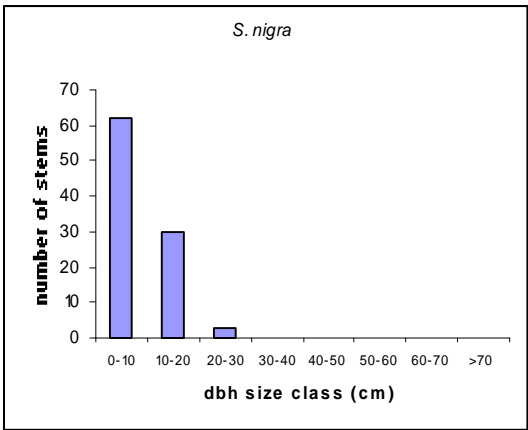


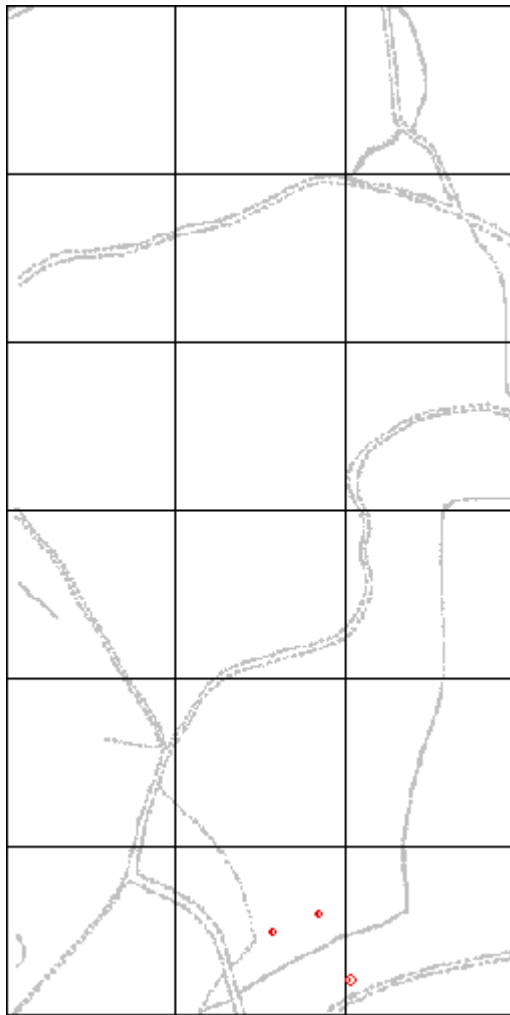


Sambucus nigra – largest stem 24.7 cm dbh



Taxus baccata – 5.9 cm dbh





Tilia x europaea – largest stem 73 cm dbh

References

- Kirby, K. J. 2010. The trees in the wood 1945-2007. In: Savill P., Perrins C., Kirby K and Fisher N. (Eds.) (in press). *Wytham Woods: Oxford's Ecological Laboratory*. Oxford University Press.
- Morecroft, M. D., Stokes, V. J., Taylor, M. E. & Morison, J. I. L. 2008. Effects of climate and management history on the distribution and growth of sycamore (*Acer pseudoplatanus* L.) in a southern British woodland in comparison to native competitors. *Forestry*, **81**, 59-74.

3 Tree heights

Tree height data are crucial for calculating a representative estimate of standing biomass, providing as they do the third dimension of stem volume (after estimating the other two from measurement of tree diameter) (Chave, 2005). We have therefore re-sampled a portion of the tree census for height. Data produced from this re-sample will be extrapolated and used with the tree census data to provide the basis for a general estimate of standing carbon stocks. (The LIDAR data (Ross Hill, CEH) also include tree heights).

Sampling design

Tree heights were measured using a stratified sample of the entire census, by species and size (Figure 3.1). Due to the dominance of only a few species in our plot, just major species were included in the sample. The two most common species, *A. pseudoplatanus* and *Fraxinus excelsior*, were each sampled 30 times in each of 5 size classes (0.5-100 mm, 100-200 mm, 200-300 mm, 300-400 mm, 400+ mm). The next most common species, *Q. robur*, *Corylus avellana* and *Crataegus monogyna*, were each sampled 30 times in total, and were not stratified for size. Whilst *Corylus avellana* and *Crataegus monogyna* are understory/shrub layer species, they nevertheless represent around a 10% of the biomass and a sixth of the total stems in our plot, and therefore are integral to any study of forest structure. Some trees were excluded from the sample if deemed to have unrepresentative characteristics that would affect height, e.g., the stem was dead, or the trunk split.

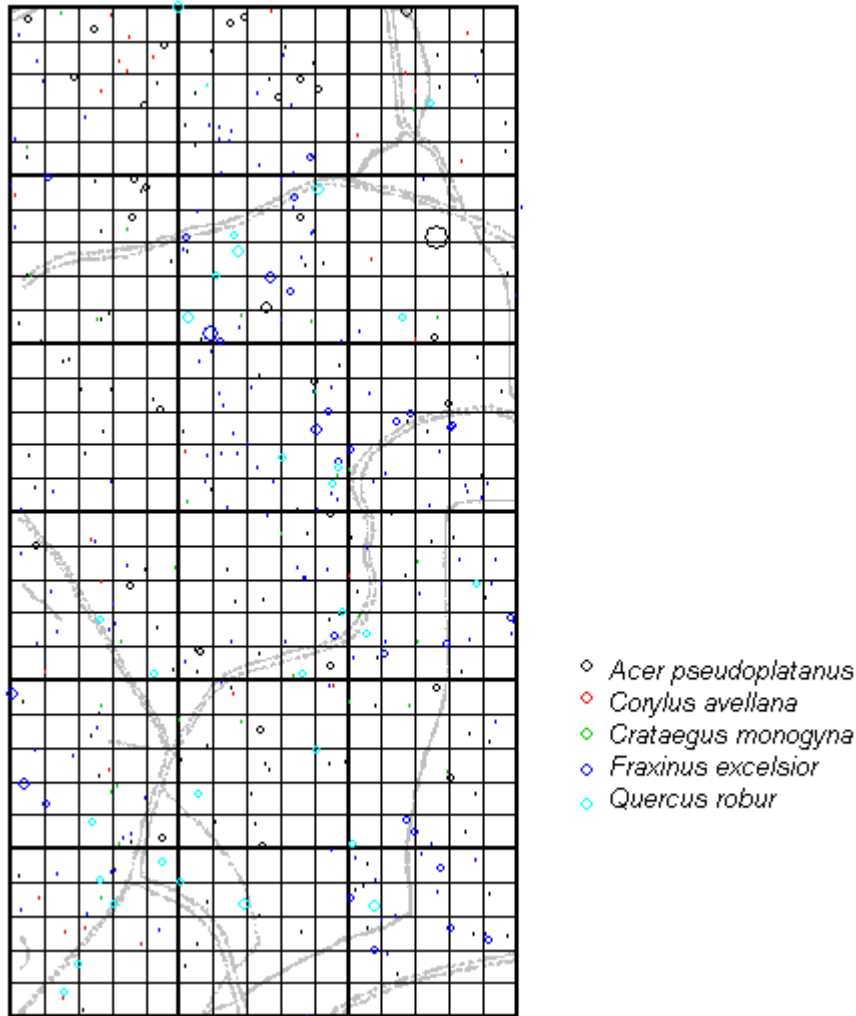
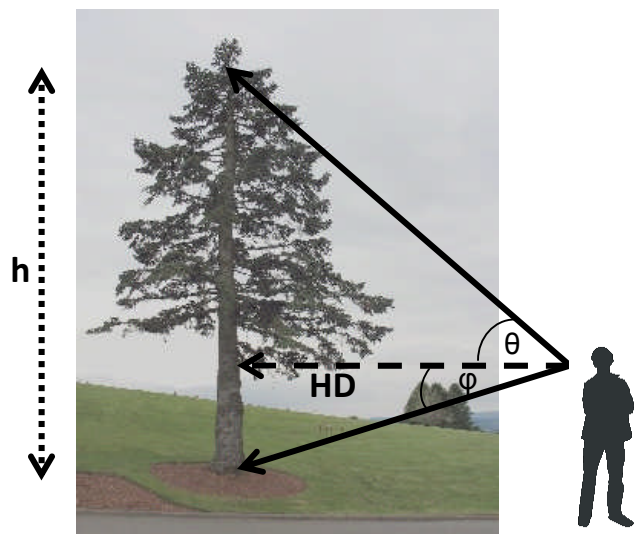


Figure 3.1: Individual trees sampled for height throughout the plot. (Symbol size is proportional to dbh – approximately ten times actual size).

Calculations

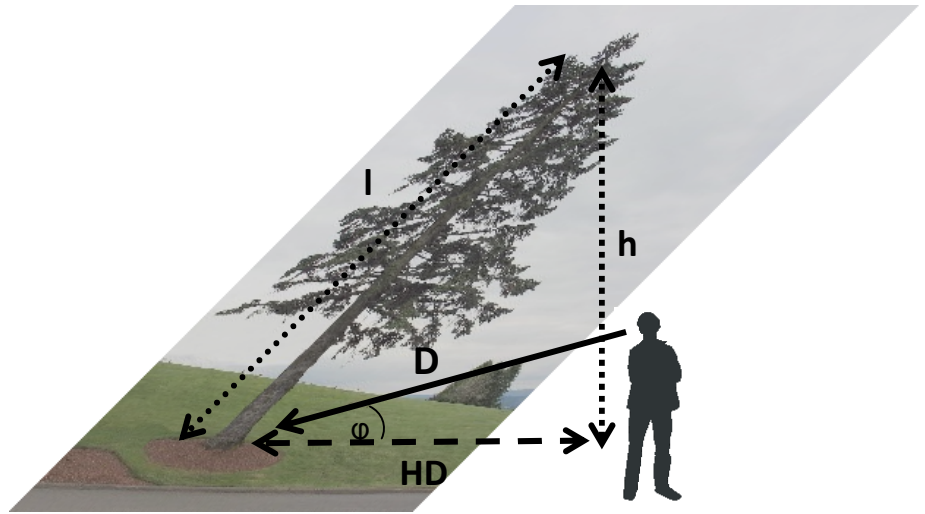
Tree height (h) was calculated using three variables: horizontal distance (HD), angle to base (ϕ) and angle to highest branching point (θ) all from a fixed point on the ground (see diagram). These variables are used to calculate height thus:

$$h = VD_1 + VD_2, \text{ and } VD_1 = HD \tan \theta \text{ whilst } VD_2 = HD \tan \phi, \text{ therefore } h = (HD \tan \theta) + (HD \tan \phi).$$



The formula accounts for measurement variance in height of measurement in relation to the stem.

Bole-length is used to estimate standing biomass rather than tree height – even though the latter is usually interchangeable with the former. In many cases though, the stems do not grow perfectly vertically, and bole-length differs from vertical distance from ground (height). In these instances a second calculation is performed to calculate bole-length from vertical distance. Horizontal distance from beneath the topmost branching point to the base of the stem is measured (a value calculated from angle to base and distance to base from point of measurement: $HD = D \cos \phi$). From this, (using Pythagoras' theorem), we can calculate bole length (l) thus:



$$l = \sqrt{(HD)^2 + h^2}.$$

Field Measurements

Each sample stem was identified using the tree census dataset: stem tag no., location, species, etc. A TruPulse 200™ laser hypsometer was used to measure the three variables required to calculate height. A point was approximately 20 m from the sample stem was used where possible, the height measurement routine was then executed with the hypsometer, as follows: a reading of horizontal distance with a laser rangefinder was first taken, then an angle to the base of tree with a clinometer, and finally the angle to topmost branching point was measured with a clinometer (this was occasionally estimated in trees such as large oaks with indistinguishable climaxes). This routine was repeated three times from different points around the stem for each sample stem. Where there was a significant slope, the base of the tree was measured at the mid-point of the slope. Where there was a significant lean ($10^\circ+$ from the vertical - although in the field this was usually assessed by eye), the HD from the base to the topmost branching point was measured and used to calculate the bole length.

Some stems lean significantly in two dimensions; these were treated as though they leaned in one dimension (as above), and extra repeats of the height measurements were taken to discount outliers.

Results

The areas of greatest bole length were concentrated in the north (lowest elevation) end of the plot, with significant regions of large bole lengths in the south east corner of the plot (Figure 3.1, left). The south east corner contains a stand of low-density mature *F. excelsior* stems, suggesting that species and maturity are important factors in bole length in the plot.

When bole length is recalculated as proportional to dbh, the regions of greatest bole-length/dbh are most pronounced in plots with low mean bole length (Fig. 3.1, right): trees that are tall relative to their dbh often occur in areas of low mean height and high stem numbers. Three significant areas are plots 9 & 10, plots 12 & 13 and plot 14; the first two contain young, dense *F. excelsior*-dominated stands, and the latter contains a young stand of coppiced *A. pseudoplatanus*. That these are areas of low mean bole length, and high bole length relative to dbh, suggests a competitive, youthful stand. Conversely, plots 16 & 17 have fewer stems, and smaller bole length/dbh relative to (plot) mean bole length, indicating larger, older trees.

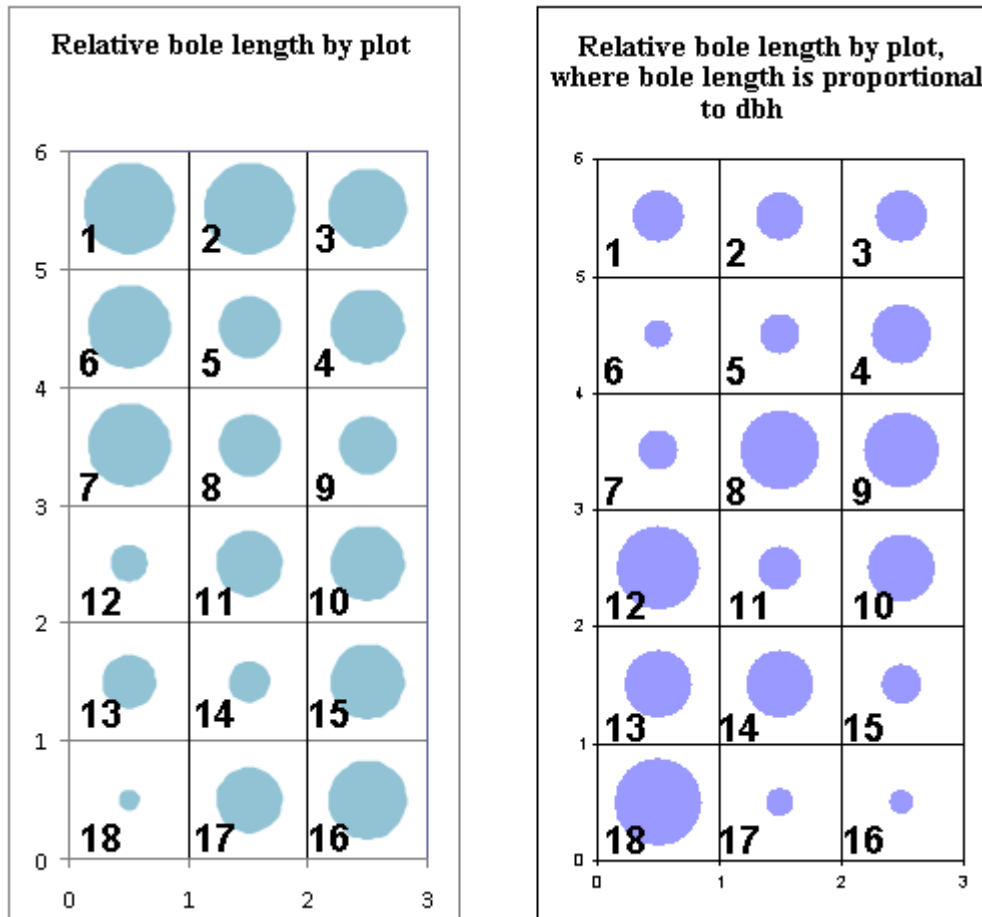


Figure 3.1: Left: Mean bole length by hectare plot; smallest is 10.9 m in plot 18 and largest 19 m in plot 2. Right: Mean proportional bole length by plot, the larger the circle, the larger the bole length/dbh relative to (plot) mean bole length; plots 12 & 13 are dominated by younger, denser stands while plots 16 & 17 have fewer, larger trees.

There is a consistent logarithmic trend in the relationship between dbh and bole length for all species (Figure 3.2), shown most clearly by *A. pseudoplatanus* and *F. excelsior* (Figure 3.2 & 3.3). Stems in the 0-10 cm and 10-20 cm dbh classes tend to have a much higher bole length dbh ratio (Figure 3.4), while the subsequent classes tend towards a lower ratio, suggesting that stems are allocating energy into growing when they are younger (lower dbh), but level off towards a maximum height (bole length) as they age (greater dbh). *C. avellana* and *C. monogyna* also show this trend, though as their maximum height is much lower (and they thus branch at a lower height) than the two dominant species, their height begins to level off by the 10-20 cm size class. *Q. robur* shows high variation around a fairly constant mean bole length of 17.9 m, however this trait is common to the general trend for stems over 40 cm dbh – almost all the stems sampled for *Q. robur* were > 40 cm dbh – illustrating that the relationship between dbh and bole length becomes weaker in mature trees, and that *Q. robur* fits the general pattern (Figure 3.5). This suggests that whilst younger (thinner) stems tend to grow in a typical pattern, probably due to competition pressures, older (wider) stems are more

susceptible to other local factors, in addition to also continuing to grow in diameter when they may have complete exposure; there is no need to grow further vertically.

Overall, bole lengths start to plateau at about 18 m and dbh at about 20 cm, which implies that canopy trees are all >20 cm dbh (Figure 3.2 to 3.6). The species bole length means fall into two categories and suggest an upper canopy of mean 17 m consisting (primarily) of *A. pseudoplatanus*, *F. excelsior* and *Q. robur*, and a understory of mean 6.9 m consisting (primarily) of *C. avellana* and *C. monogyna* (table 3.1). *F. excelsior* has slightly longer boles than *A. pseudoplatanus* for the same dbh (Figure 3.2). Whilst variation between bole length and tree height was taken into account, in effect this variation only accounted for a 1.3% difference between the two: whilst bole length has been used here, the data can also be used to draw conclusions about tree heights in the plot.

Table 3.1: Mean bole length by dbh, species and by dbh for selected species.

Mean bole length (m) by		
(i) size category		Bole (m)
0-10		7.4
10-20		13.4
20-30		18.4
30-40		19.7
40+		20.5
(ii) species		
<i>A. pseudoplatanus</i>		15.6
<i>F. excelsior</i>		17.4
<i>C. avellana</i>		7.6
<i>C. monogyna</i>		6.2
<i>Q. robur</i>		17.9
(ii) <i>A. pseudoplatanus</i> & <i>F. excelsior</i> by size		
<i>A. pseudoplatanus</i>	0-10	7.8
	10-20	13.1
	20-30	17.3
	30-40	18.8
	40+	21.2
<i>F. excelsior</i>	0-10	9.2
	10-20	15.2
	20-30	19.5
	30-40	20.9
	40+	22.2

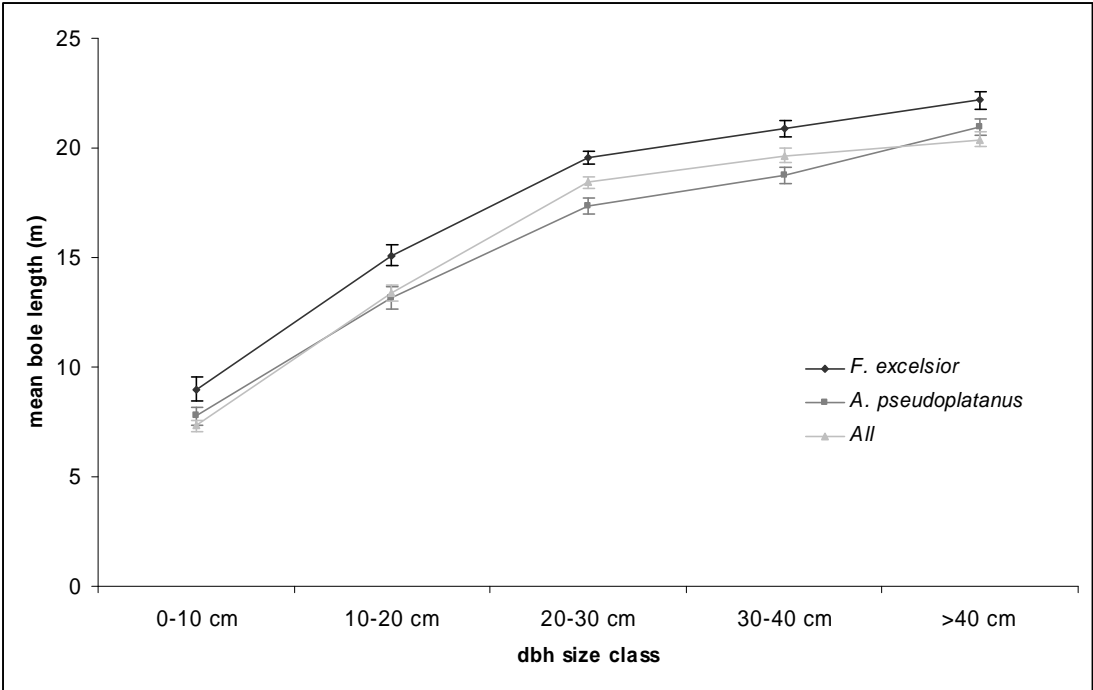
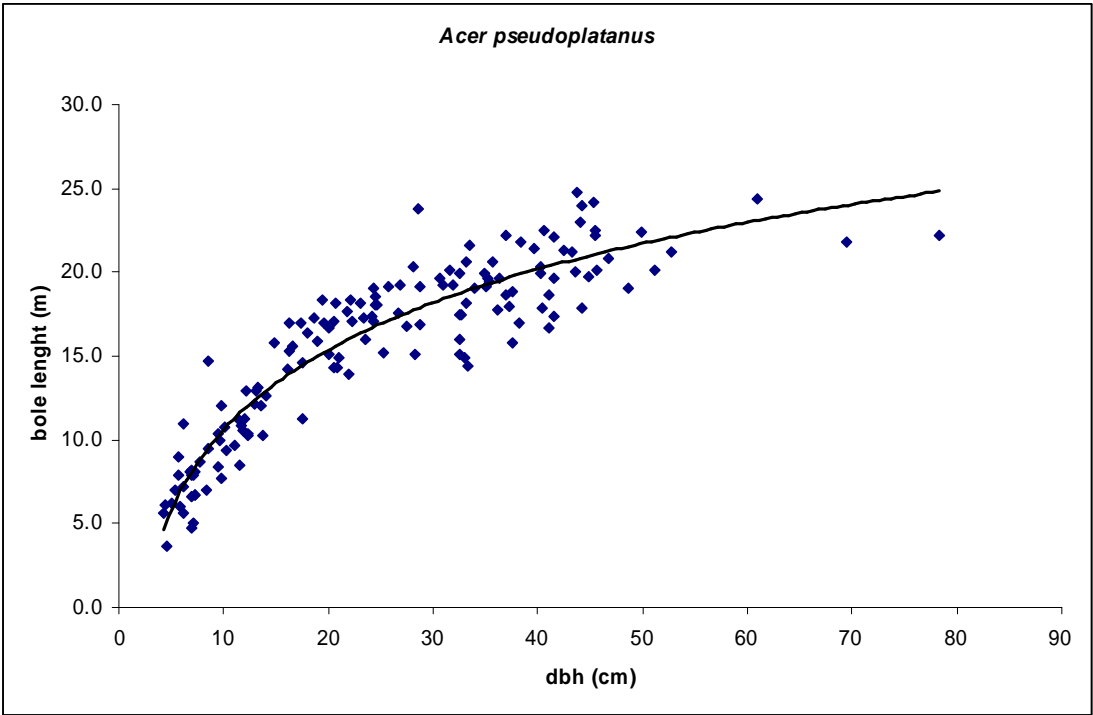
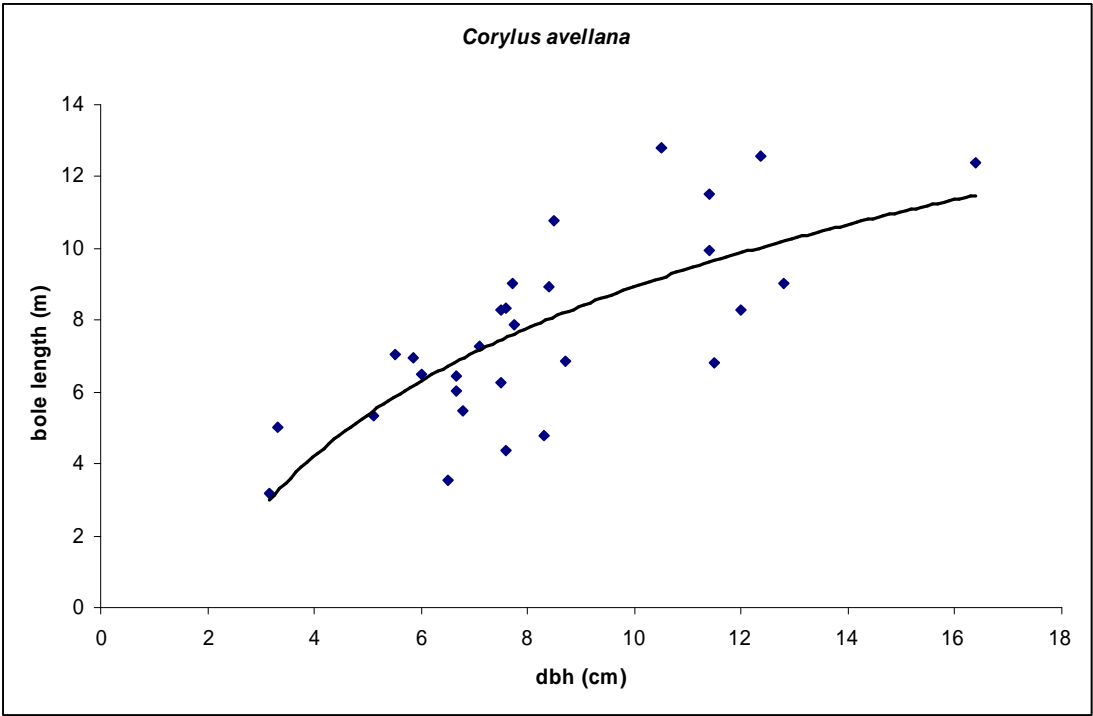
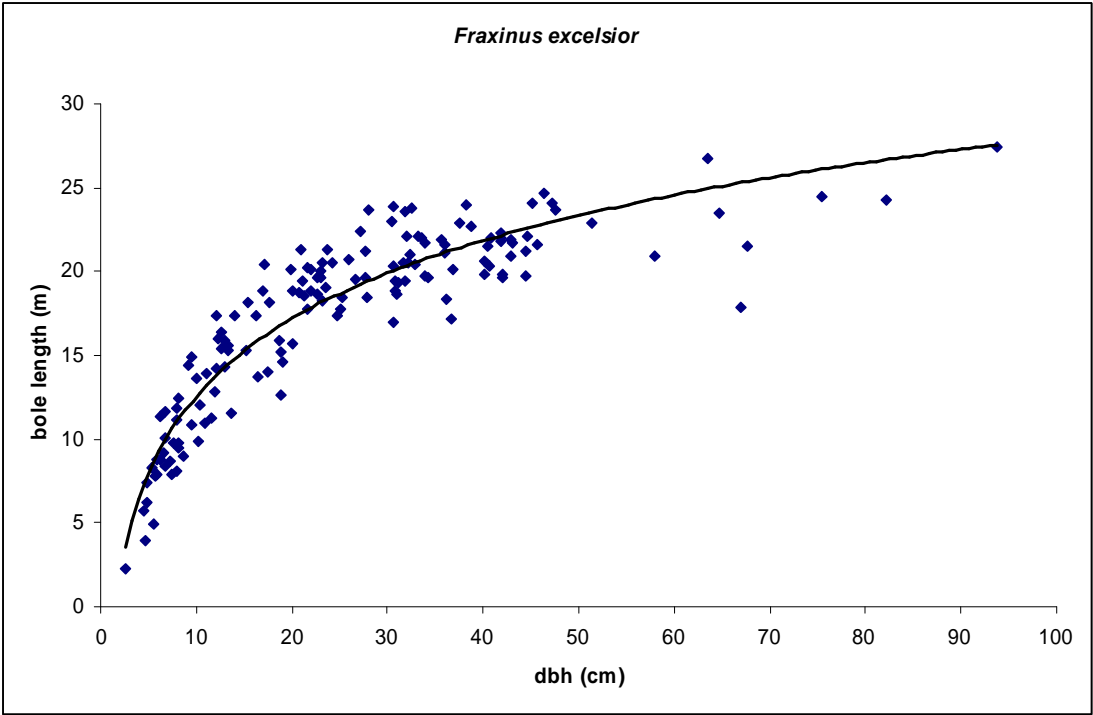


Figure 3.2: Change in bole length with size class for *A. pseudoplatanus*, *F. excelsior* and all species combined.





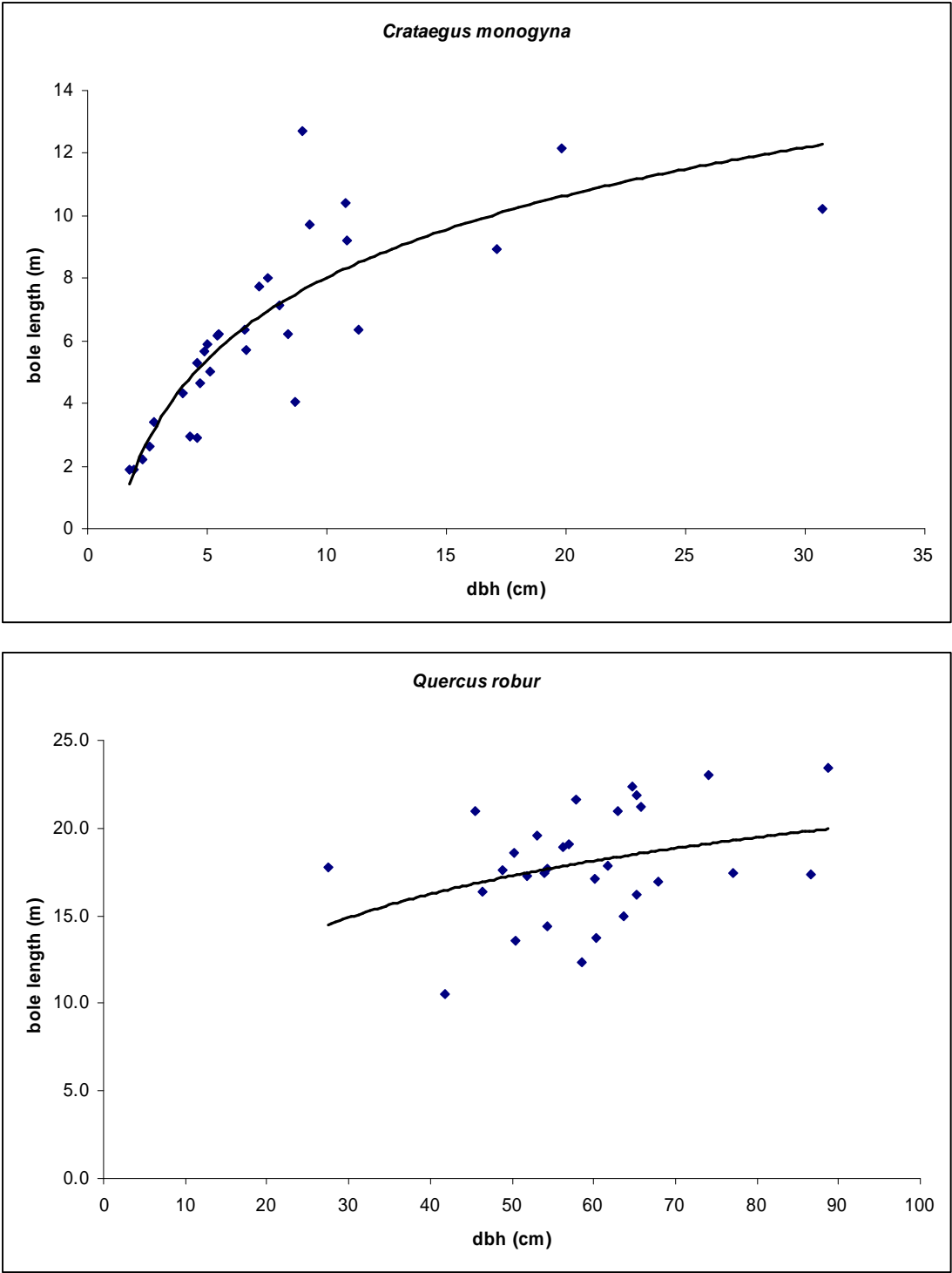


Figure 3.3: Relationship between dbh and bole length by species.

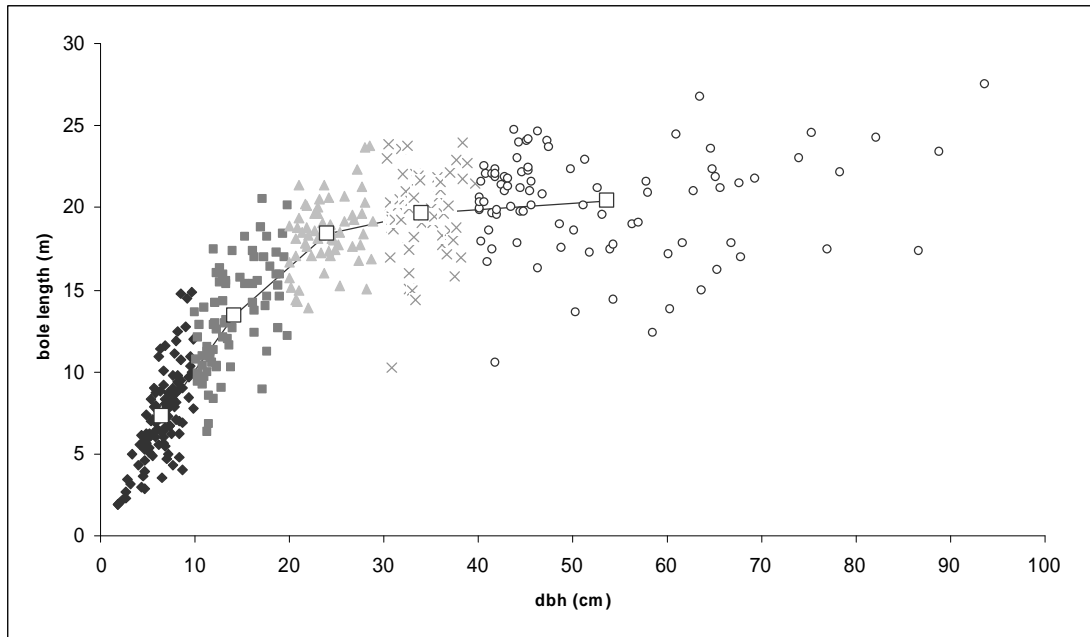


Figure 3.4: Relationship between dbh and bole length by size class. White squares indicate size class mean.

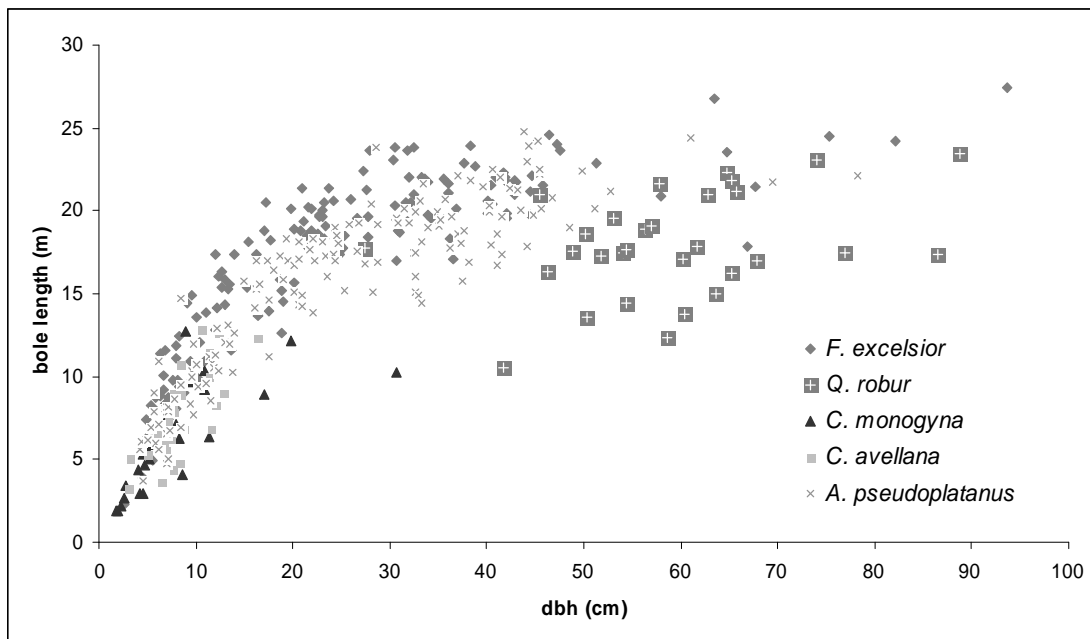


Figure 3.5: Relationship between dbh and bole length by species.

References

- Chave, J. (2005) *Measuring tree height for tropical forest trees: A field manual for the CTFS sites*. CTFS Global Forest Carbon Research Initiative.
<http://www.edb.ups-tlse.fr/equipe1/chave/tree-height-protocol.pdf>

4. Coarse woody debris

An inventory of woody debris was undertaken in the plot, with the aim of providing an estimate of the coarse and fine woody debris pool size within the plot. Coarse woody debris can often account for 5-10% of forest carbon stocks (Larjavaara and Muller-Landau, 2009); it is thus essential that it is represented in any assessment of plot carbon stocks. Our plan followed aspects of the CTFS woody debris protocol (Larjavaara and Muller-Landau, 2009), with some differences with regard to intensity of survey, exclusion of destructive methods, and assessment of decay. The most significant difference is that we are estimating the current carbon pool only as there is no annual plot reassessment plan in place for the repeated measurement of interannual pool size flux, system inputs and outputs. We define woody debris according to CTFS protocol.

Sampling Design

The woody debris pool size was estimated through intensive sampling along line-intercept transects, a time-efficient and inclusive method of debris sampling (Waddell, 2002). Three long transects of 600m were used, running parallel from south to north through the plot, with Transects 1, 2 and 3 located 50 m, 150 m and 250 m, respectively, from the plot’s western edge (Figure 4.1). This provides a total sample of 1800 m, smaller than CTFS standard, due to the intensity of our sampling procedure (see below) and the time constraints.

Sampling along each transect involved measuring any piece of fallen debris that crosses the transect line, at all points of intersection (if more than one). Pieces of woody debris that do not touch the ground at the point of intersection, but touch at some point are included, pieces that do not touch the ground at any point are excluded.

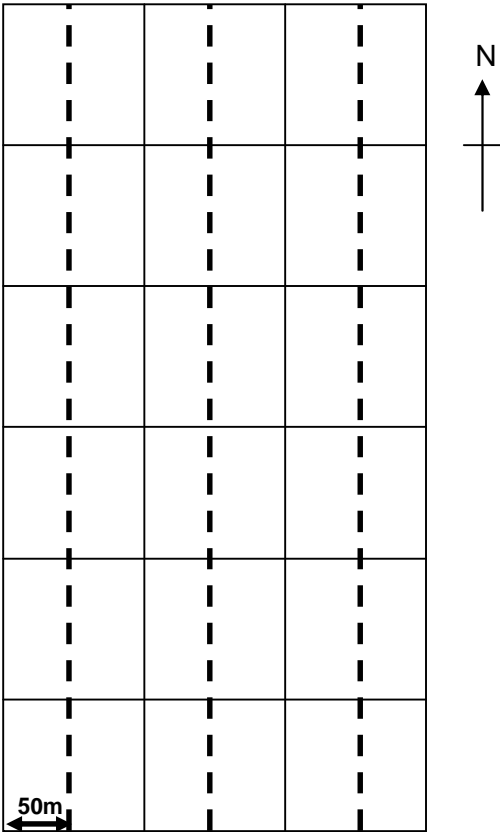


Figure 4.1: Transect locations.

Along each transect we sampled every piece of debris of diameter 10 mm and above, as CTFS protocol for standing biomass recommends recording all stems of this diameter and above.

This therefore includes sub-fine woody debris (10-19 mm), fine woody debris (20-199 mm) and coarse woody debris (200+ mm) (Larjavaara and Muller-Landau, 2009). While this is more intensive than CTFS debris protocol, it enables a direct comparison of standing to fallen carbon stocks, and in a temperate plot with lower productivity and lower turnover rate than that of a tropical forest, carbon will remain in the debris phase for longer, and therefore the smaller samples of debris become more significant carbon stores - it is important they are represented.

Field Measurements

Transects were marked out using a 100m tape, compass and marker cane. The tape was drawn tight and flat to the ground along a northward bearing up to 100 m, at which point a marker cane was fixed. Starting at the southern edge, measurements were taken of each piece of debris that intersected the tape. Pieces must cross at least half the tape's width to be included.

For each piece of debris: (i) it was identified to species, if possible (this is very difficult with significantly decayed pieces), or labelled 'unidentified'; (ii) its diameter was recorded at the point of intersection with the tape using a diameter tape, measured at right angles to the long axis of the piece, regardless of its orientation in relation to the tape (Figure 4.2). For pieces embedded in the ground, and for pieces with little or no structural integrity, the diameter was estimated by marking either edge of the sample with a vertical cane, then measuring the width between the two canes; (iii) its degree of decay was then measured on a 1-5 scale (Baker *et al.*, 2007).



Figure 4.2: Woody debris transect tape and measurement.

This scale measures decay by appearance, amount of bark intact, resistance to a nail being pushed into the piece and structural integrity, as follows:

Class 1: solid wood, recently fallen, with intact bark and fine branches still attached;

Class 2: solid wood, but with no fine branches, and bark starting to fall off;

Class 3: non-solid wood, in poorer condition, but where it was still difficult to push a nail into the wood by hand;

Class 4: soft, rotten wood, where a nail could be pushed into the wood easily;

Class 5: soft, rotten wood, which collapsed easily when pushed by hand.

The scale provides a simple in-field assessment of relative decay and the classes can then be analysed for their relative carbon content, to provide a unique classification system for the Wytham plot. After sampling each piece is returned to the forest floor.

Calibration of wood density

The debris pieces measured in the field required calibration to give an estimated value of carbon weight/unit volume for different decay classes, different species, and finally the debris stocks for the whole plot.

A subsequent survey was therefore required to obtain a debris sample for calibration. Randomly-sampled sections of transect were revisited to acquire samples, with sites of rare debris being actively selected so as to include a representation of all species and decay classes represented in the larger sample. Five samples were collected for every decay class of each species represented in the survey (this includes *Acer pseudoplatanus*, *Fraxinus excelsior*, *Quercus robur*, *Corylus avellana*, *Crataegus monogyna*, *Acer campestre*, *Salix* spp. all categories 1-5; *Fagus sylvatica* categories 1-3 & 5; *Betula* spp. categories 1-4; *Sambucus nigra* category 3 only). Where this was not possible, either a single sample was used for a class (*Crataegus monogyna* categories 4 & 5) or the class was left unrepresented in the calibration process (*Salix* spp. categories 1 & 5). Easily transportable pieces were usually selected, and a saw used to remove transportable sections where none was available.

Laboratory analysis

Each sample was cut to a 50 mm length, and the diameter measured at each end to give sample volume. During this stage, pieces of the sample that fall off during cutting were retained and kept together with the bulk of the sample (on a dish of known weight). Samples were then dried at 65°C for several days and then weighed. The samples were analysed chemically for carbon density (g/cm³). From the large calibration sample, one sample in each

decay class of the three major species, *Acer pseudoplatanus*, *Fraxinus excelsior* and *Quercus robur*, was milled and sent (to the Macaulay Institute, Aberdeen) for chemical analysis of carbon content (Dumas combustion).

The resulting carbon by weight (C/g) values were applied to the transect data as follows: firstly, density (g/cm^3) values were calculated by applying the dry weight (g) to wet volume (cm^3) ratio calculated from the full range of samples taken from the field. Using the density (g/cm^3) ratio and the C/g values from the chemical analysis, carbon stocks by volume of various species and decay classes were derived.

The assumption was that the sample transects each accounted for 1 cm of the plot width, and that each piece of CWD measured is a cylinder of length 1 cm. This principle of using a 'strip sample' is borrowed from van Wagner (1982). We therefore produced the volume of each debris piece from its diameter using the formula for the volume of a cylinder ($\pi(d/2)^2l$), where d is diameter and l is length, disposing with the redundant 'l' term. By multiplying this term by the carbon-by-volume for species and class calculated above, carbon-by-volume (g/cm^3) values for each piece were calculated.

To convert these carbon values to a usable estimate of carbon stocks, the carbon-by-volume values were summed to produce a total sample carbon value, then divided by the sample area (given as in cm as 1 x the sum of the sample transects) and converted to m ($\times 10000$) to give a C/unit area value (g/m^2). Two useful values can be derived from this: the total plot stocks (C/unit area \times plot area(m^2)) in g and a standard C/unit area value ((Total plot stocks/sample area(m)) given in Mg/ha.

Summary of the calculations:

- (1) Mean carbon concentrations by weight for each species and decay class (g/cm^3):
 $(\sum(m/v)/n)c$ of each size class for each species in the calibration sample, where n is no. of pieces, m is dry mass (g), v is wet volume (cm^3) and c is % carbon stock of each species and decay class.
- (2) Total sample carbon stocks (g): $\sum (\pi(d/2)^2s)$ for each piece, where d is diameter (cm) and s is the mean carbon concentrations by weight for species and decay classes, calculated in (1).
- (3) Conversion of total sample carbon stocks to standard carbon weight/unit area (Mg/ha):
 $C/a \times 10^{-2}$, where C is the measured carbon stock (g) over the sample area a (m^2)

Comparative study

Nested within this plot is a long-term forest dynamics plot monitored for debris during 2005 (Fenn, unpublished data), (hereafter called ‘the 2005 survey’). This 1 ha plot is located in the north western corner of the 18 ha plot. The data produced by it can be used to underpin any conclusions we reach about the level of woody debris found in the larger plot as a whole. The debris survey on this plot used the same basic line-intersect method (see van Wagner, 1982) as our survey, and so should be directly comparable, albeit with a few caveats: (1) the survey was made over a single hectare plot, and consisted of eight 100m transects, four running north-south at 100m intervals through the plot and four running east-west also at 100m intervals; (2) the 2005 survey did not use a consistent assessment of decay state in its final analysis, nor did it have an assessment of the variations in carbon content by species and decay state. Therefore, for the larger plot a mean decay state and carbon content was assumed and applied this to the whole sample; (3) the 2005 survey only sampled debris of diameter ≥ 50 mm, whereas we went down to debris of diameter ≥ 10 mm. To compensate for this, the standardised carbon value was scaled up using an assumed value of carbon ignored by not including pieces < 50 mm. This scaling value was calculated using the percentage of carbon in the larger survey that was attributed to pieces under 5 cm, and was 29.3% of the whole

Results

The chemical analysis returned carbon concentrations of 44-50% of the total debris dry weight across species and decay classes. The overall mean carbon concentration was 47.79% (± 0.40 SE, st. dev. 1.53) (Table 4.1). There was a general decrease in carbon % with decay class (Figure 4.3), however, *Fraxinus excelsior* tends to increase with increased decay.

Table 4.1: Carbon density variation by species.

species	Mean C (%)	Standard deviation	Standard error
<i>F. excelsior</i>	49.07	1.02	0.46
<i>Q. robur</i>	47.40	1.05	0.47
<i>A. pseudoplatanus</i>	46.89	1.69	0.76
All	47.79	1.53	0.40

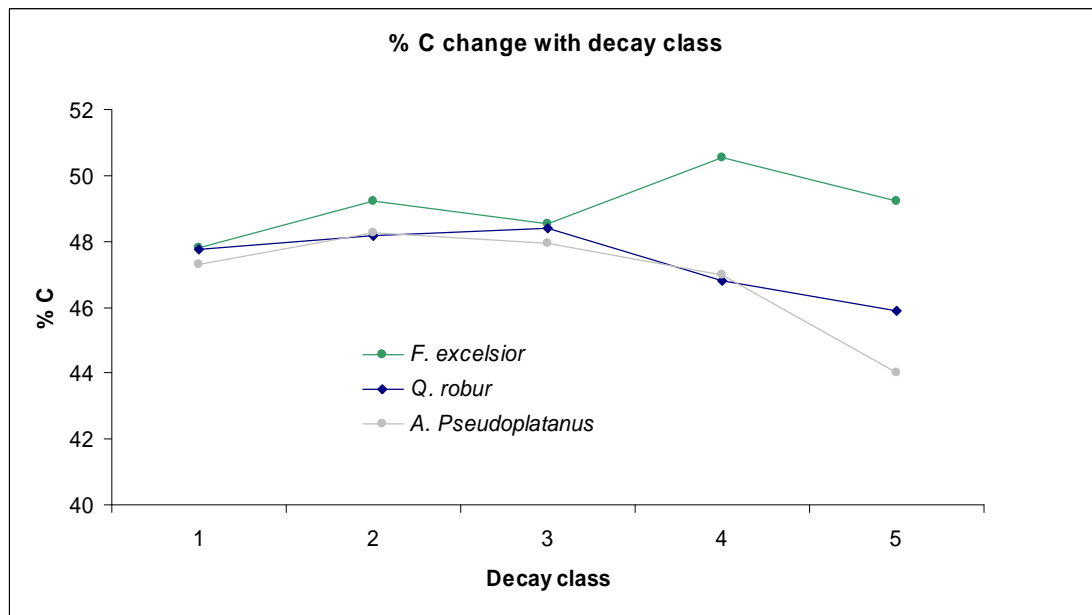


Figure 4.3: Carbon content as a function of decay.

As carbon concentration generally keeps close to a mean value, ‘decay class’ can be interchanged with dry weight loss when considering loss of carbon with decay. Dry weight wood density decreased steadily and significantly with decay class, with a 0.33 g/cm^3 drop from decay class 1 to class 5 (Table 4.2).

Table 4.2: Change in biomass by decay class.

Decay class	Sample mass/vol (g/cm^3)
1	0.512
2	0.425
3	0.325
4	0.219
5	0.185

There was high inter-species variation in biomass and carbon content (Figure 4.6). While the biomass levels of fresh debris (decay class 1) varied from 0.699 g/cm^3 (*F. sylvatica*) to 0.398 g/cm^3 (*A. pseudoplatanus*), the most decayed samples (decay class 5) varied only across a range of 0.083 g/cm^3 , from 0.224 g/cm^3 (*A. campestre*) to 0.141 g/cm^3 (*F. sylvatica*). Biomass for all species decreased with decay class.

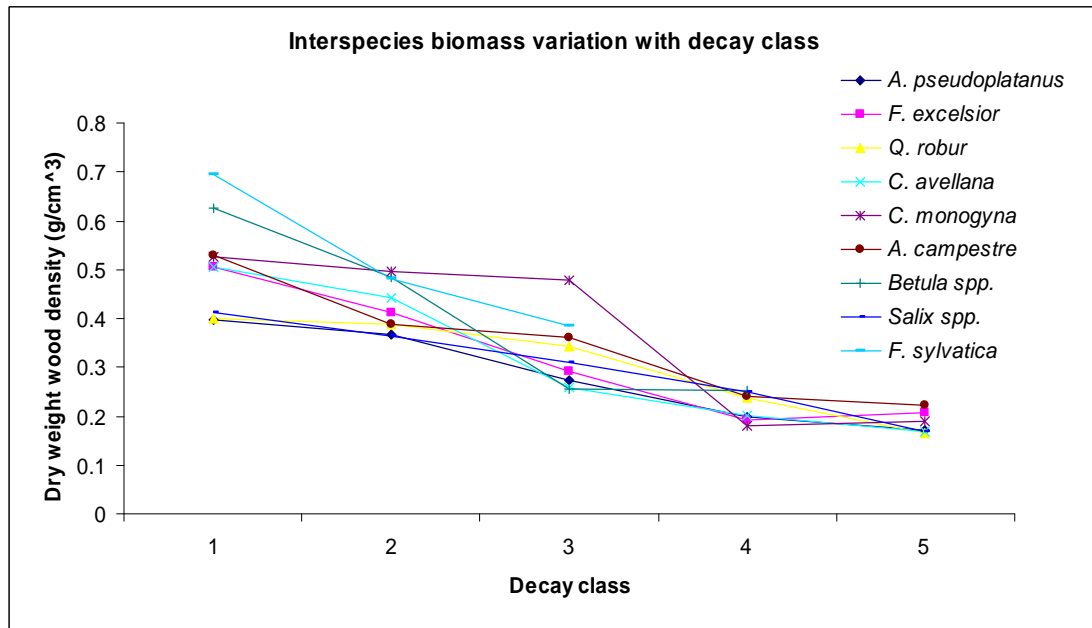


Figure 4.6: Biomass as a function of decay class (all species)

The survey produced a total plot debris biomass of 133 Mg, which approximates to 7.38 Mg/ha. Of this, total plot carbon stock was 64.2 Mg, approximating to 3.57 MgC/ha. The sample mean biomass was 3.78 g (± 0.50 SE), while the sample mean carbon stock was 1.83 g (± 0.24 SE).

The plot results can be compared to the 2005 data from the 1 ha carbon dynamics plot nested within our larger plot. That survey returned a biomass value of 2.44 Mg/ha and a carbon stock value of 1.17 Mg/ha. To align the two datasets, the discrepancy in sample piece lower limit, as described above, was accounted for. This compensation gave a new biomass value of 3.46 Mg/ha and a carbon stock value of 1.64 MgC/ha. The sample mean biomass for this study was 27.95 g (± 3.93 SE), while the sample mean carbon stock was 13.36 g (± 1.88 SE).

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5 Soil survey

Wytham Woods lies on neutral clay soils of varying permeability: Rendzina, Brown Earth and Surface Water Gley (as described by Avery, 1980). The 18 ha plot contains three soil series (as previously surveyed for baseline information for the ECN; Beard, 1992, unpublished soils map): Denchworth, Moreton and Sherbourne, distributed in the plot as below (Figure 5.1). The soil depth varies through the plot, with the Denchworth the deepest in the lower part of the plot, and the shallowest soil in parts of the southern end of the plot, at the top of the hill. The Denchworth soil grades into the underlying clay which is probably deeper than 50 cm in places and is stone free and non-calcareous above 50-60 cm; the Moreton soil has been recorded up to 40-50 cm, but it is stony, calcareous clayey soil over limestone to 30 cm, while the Sherbourne soil type is nowhere deeper than 30 cm. Generally, the soil horizons are approximately 10 cm in most cases: the A horizon is 0 – 10 cm; the B horizon 10 – 20 cm, and; the C horizon 20 – 30 cm.

Soil surveying methods followed Brady & Weill (2008) and the CTFS protocols (Harms *et al.*, 2004).

Sampling design

The 91 sites for the soil sampling are every 50 m along both the N-S and E-W axes of the large plot (Fig. 5.1). There was a small adjustment to this grid system with four of the sites moved slightly out of position in order to more equally represent all soil types in the plot. Soil samples were collected for carbon + nitrogen analysis for all sites, and nutrient analysis (P, K, Ca & Mg) at 40 sites (with more or less comparable representation of the three soil types), at various depths corresponding to the soil horizons (Figure 5.2).

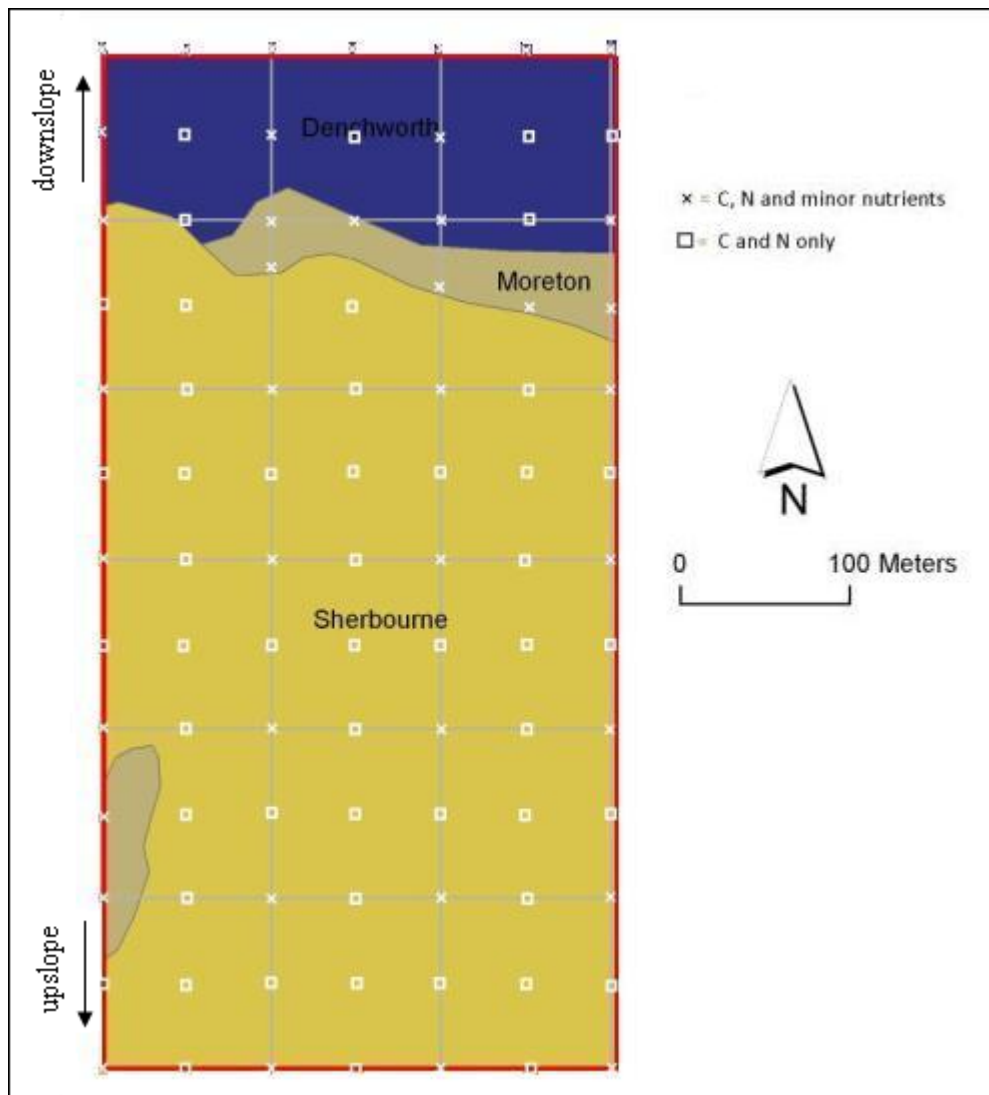


Figure 5.1 Location of the soil sampling sites and distribution of the soil series in the plot.



Figure 5.2: Extracting soil cores.

For the 51 sites which were analysed for carbon + and nitrogen only, we collected a mixed sample across the soil profile of 0-30cm depth. For the 40 carbon + nitrogen and minor

nutrients sites we collected three separate soil samples at different depths (0-10cm, 10-20cm and 20-30cm), in order to ascertain change in chemical characteristics with depth. In some cases the soil was too shallow to follow the 10 cm horizon format rigidly and we approximated the horizons according to colour and texture of the soil. At all 91 sites we collected a 10cm soil core for analysis of physical properties (texture, bulk density and porosity). We obtained the samples using a steel corer and a shovel. All samples were dried, the C + N samples were milled to powder and the nutrient samples sieved to 2 mm. Chemical analyses were carried out at the Macaulay Institute in Aberdeen, Scotland, physical analysis were carried out on site (in the Wytham Field Station laboratory).

Physical properties

Soil texture

Soil texture was analysed according to Brady & Weill (2008), using walnut-sized pieces of soil and following the soil texture class criteria. The soil is moistened and then assessed for its feel and how well it can be drawn out into a ribbon. The classification is as follows (Brady & Weill, 2008):

1. Soil will not cohere into a ball, falls apart: **sand**
2. Soil forms a ball, but will not form a ribbon: **loamy sand**
3. Soil ribbon is dull and breaks off when less than 2c.5cm long and
 - a. Grinding noise is audible; grittiness is prominent feel: **sandy loam**
 - b. Smooth, floury feel prominent; no grinding audible: **silt loam**
 - c. Only slight grittiness and smoothness; grinding not clearly audible: **loam**
4. Soil exhibits moderate stickiness and firmness. Forms ribbons 2.5 to 5cm long, and
 - a. Grinding noise is audible; grittiness is prominent feel: **sandy clay loam**
 - b. Smooth floury feel prominent; no grinding audible: **silty clay loam**
 - c. Only slight grittiness and smoothness; grinding not clearly audible: **clay loam**
5. Soil exhibits dominant stickiness and firmness, forms shiny ribbons longer than 5cm, and
 - a. Grinding noise is audible; grittiness is dominant feel: **sandy clay**
 - b. Smooth floury feel prominent; no grinding audible: **silty clay**
 - c. Only slight grittiness and smoothness; grinding not clearly audible: **clay**

Bulk density & porosity

Bulk density was calculated by drying and weighing a sample of known volume, and dividing the weight by volume to give a density value (g/cm^3). Volume was ascertained by filing a

10cm-long section of the soil corer with water, then measuring the volume of water held in this space (volume = 32 ml). Samples were dried at c. 50°C overnight and then weighed.

Porosity was calculated after Brady & Weill (2008):

% pore space = $100 - ((\text{bulk density Mg/m}^3 / \text{particle density Mg/m}^3) \times 100)$, where particle density is assumed to be 2.65 mg/m³ for most silicate-dominated mineral soils.

Chemical analyses

C and N content: the total nitrogen and carbon content of the samples was determined by an automated Dumas combustion procedure (Pella and Colombo, 1973) using a Flash EA 1112 Elemental Analyser, (Thermo Finnigan, Italy).

Plant Available Nutrients: nutrients, considered to be that fraction available for plant uptake, are extracted from the soil using 0.43 M acetic acid. The concentrations present in the soil solution are determined using Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES).

Results

The combination of chemical and physical analyses provides a stratified picture of soil variation within the plot. These data will enable us to estimate current soil carbon stocks in the wood, and compare with other surveys of similar temperate woodlands, such as the Countryside Survey, and in future we can investigate changes over time in both carbon and other soil nutrients.

Soil texture

The predominant soil texture across the whole plot was clay, about 60% (Table 5.1, Figure 5.3). Silty clay was the second most common with 22%, clay loam made up 15% and silty clay loam < 5%. Soil texture varied with depth: the top horizon had the most organic content (loam) as would be expected, while the clay content increased with depth (Table 5.2, Figure 5.4). Silty clay loam accounted for 50% of the top layer of soil while clay made up 80% of the deepest layer.

Table 5.1: Soil texture types by site.

Soil texture	Number of sites (of 91)
Clay	53
Clay loam	14
Silty clay	20
Silty clay loam	4

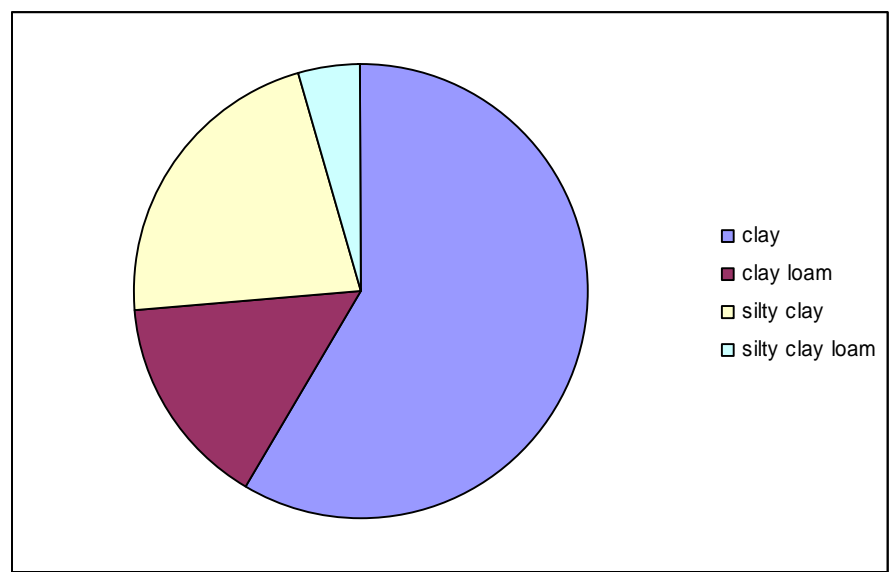


Figure 5.3: Soil texture for all sites.

Table 5.2: Soil texture type by depth.

Soil texture	Soil depth		
	0-10 cm	10-20 cm	20-30 cm
Clay	3	21	32
Clay loam	6	2	0
Silty Clay	11	15	5
Silty Clay Loam	20	2	0

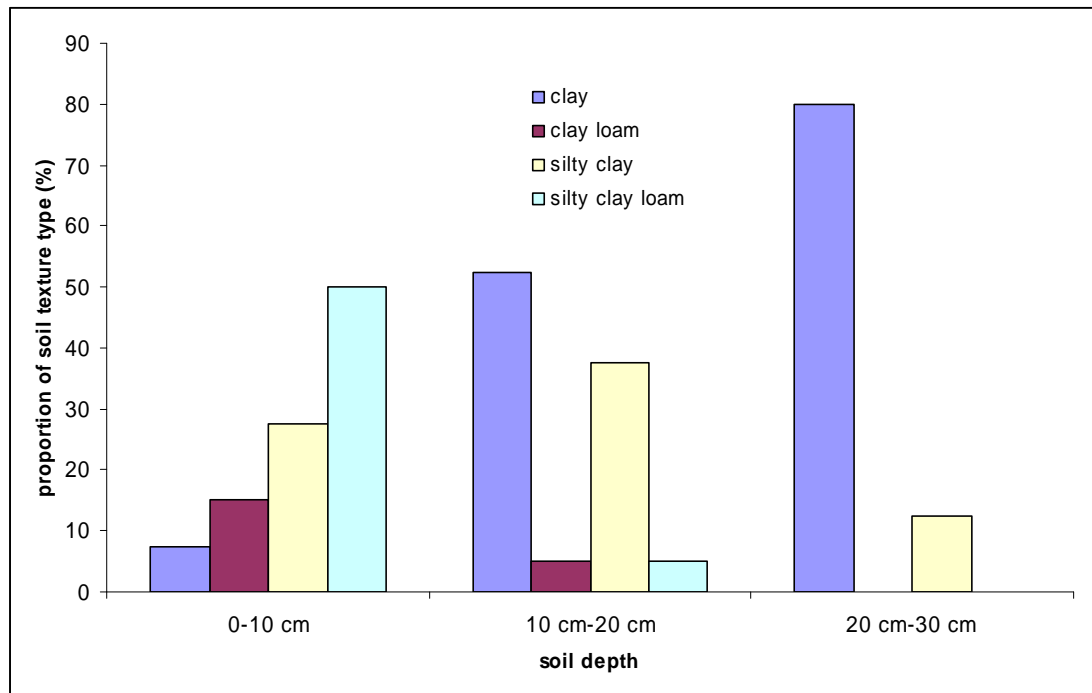


Figure 5.4: Soil texture by depth.

Separating soil textural types according to the three soil series in the plot, silty clay loam dominates the Denchworth soil, silty clay dominates the Moreton soil, and clay is the predominant texture in the Sherbourne soil (Table 5.3, Figure 5.5). The soil thus becomes more clay rich with increasing altitude/slope.

Table 5.3: Soil texture by soil type.

Soil texture	Soil type		
	Denchworth	Moreton	Sherbourne
Clay	2	1	32
Clay loam	--	--	18
Silty Clay	5	5	7
Silty Clay Loam	10	2	9

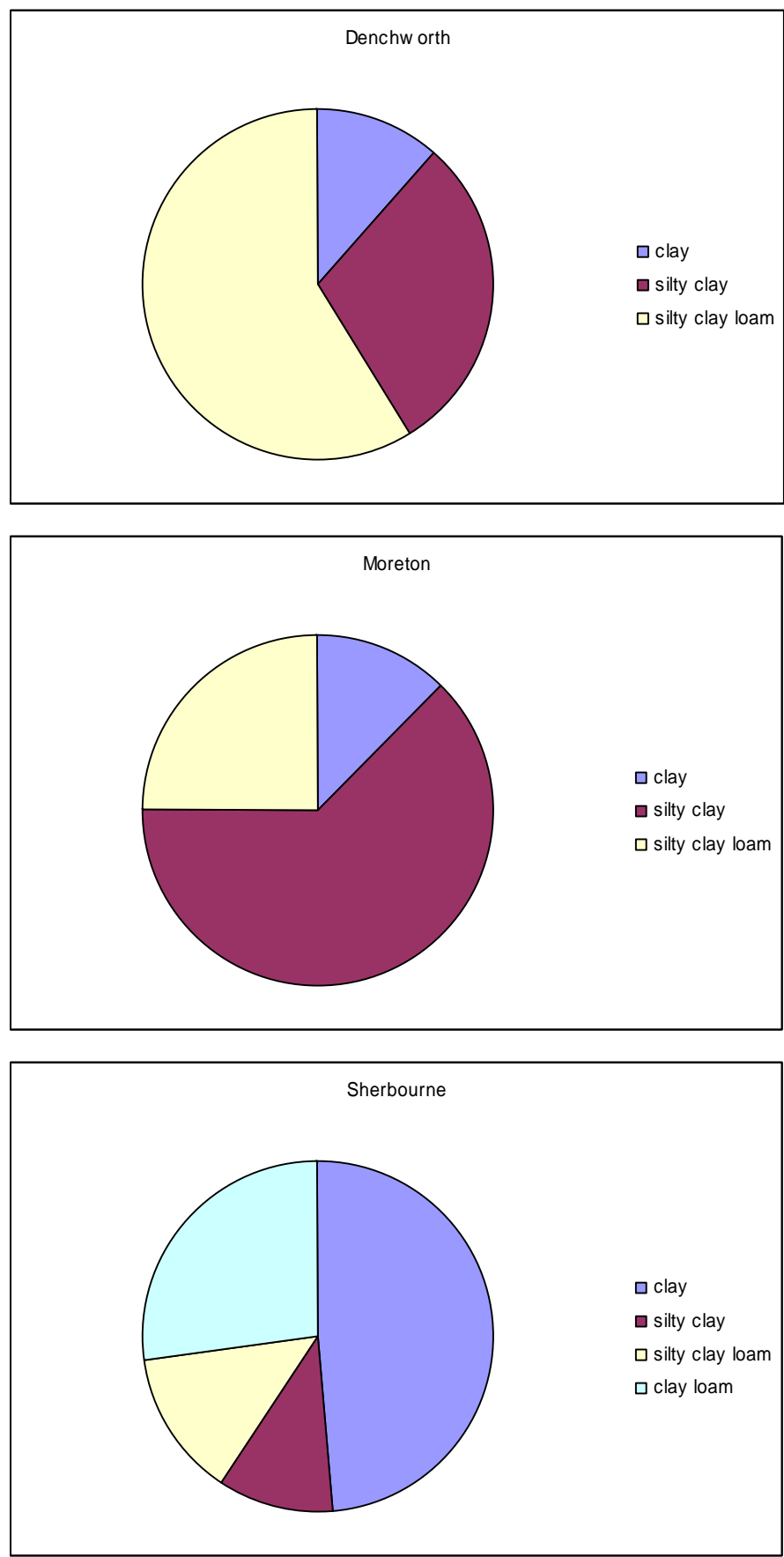


Figure 5.5: Soil texture by series.

Bulk density & porosity

The Moreton and Sherbourne series are very similar in terms of bulk density and porosity whereas the Denchworth soil, on the lower part of the hill, had significantly higher bulk density and lower porosity (Table 5.4, Figure 5.6). The bulk density ranged from 0.9 to 1 Mg/m^3 and pore space from 60% to 66%.

Table 5.4: Bulk density and porosity by series.

	Bulk density (Mg/m^3)	Porosity (% pore space)
Moreton	0.909	65.7
Sherbourne	0.907	65.8
Denchworth	1.054	60.2

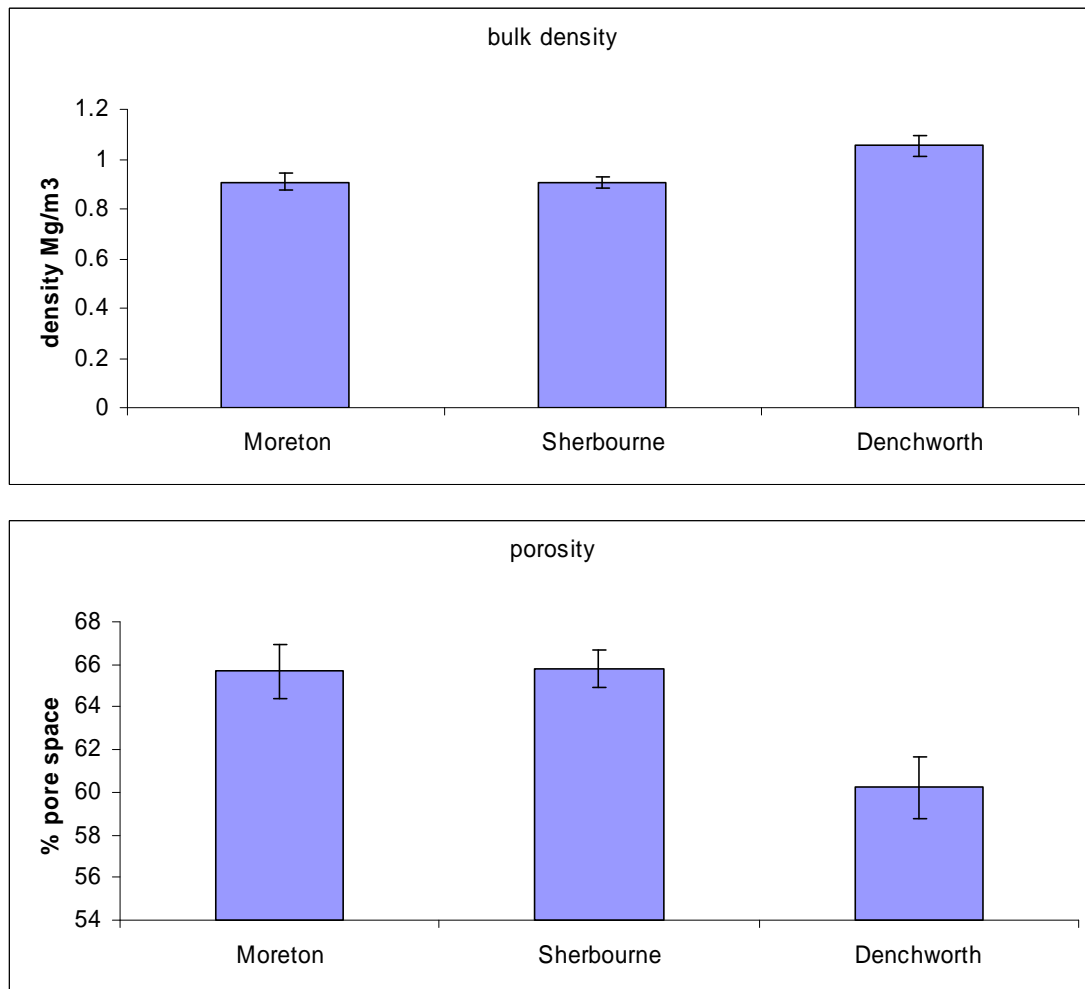


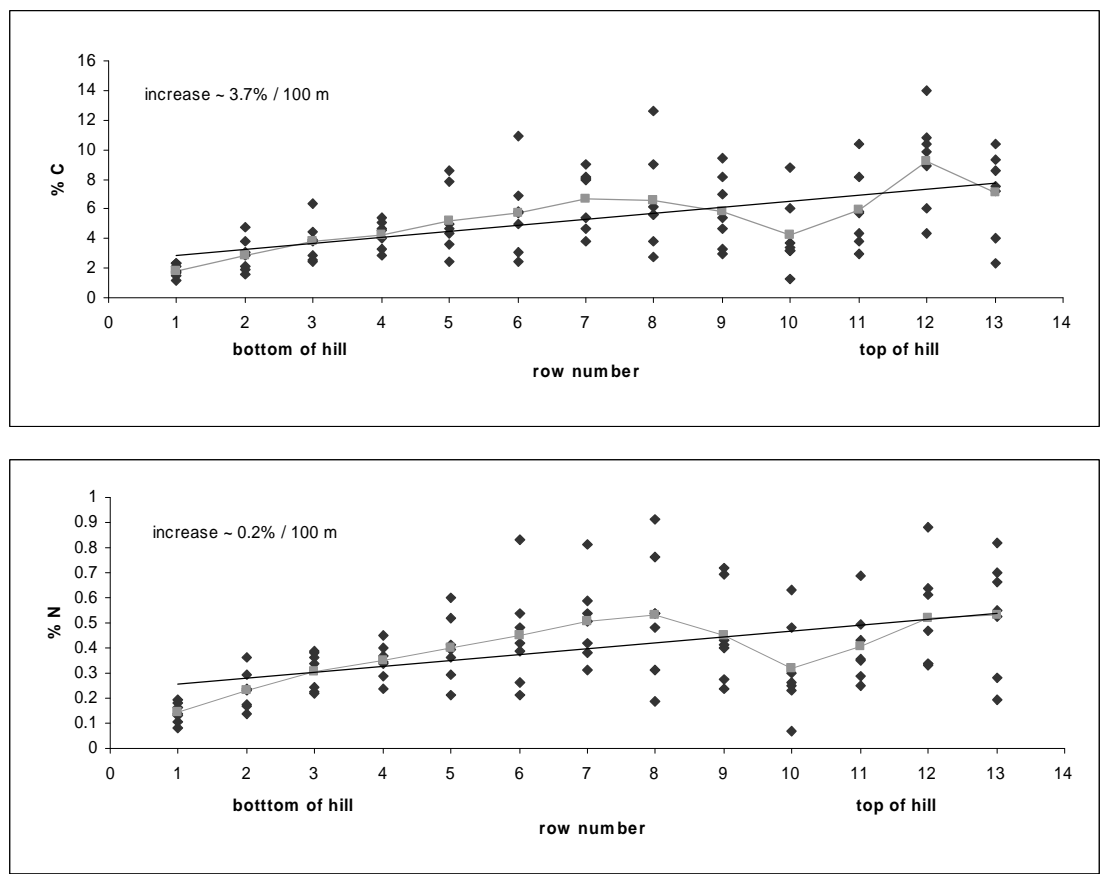
Figure 5.6: Bulk density and porosity for the three soils.

Carbon, nitrogen and micronutrient analysis

There is a clear increase in both the mean value and variation with increasing altitude (Table 5.5, Figure 5.7). For the whole plot, the mean soil carbon proportion is 5.32% (SE 0.29), and the nitrogen proportion is 0.395% (SE 0.02). This gives a mean plot C:N ratio of 13.47 (Fig. 5.7).

Table 5.5: Carbon and nitrogen proportion and C:N ratios by sample site (row means).

Row number	C%	N%	C:N ratio
1	1.84	0.14	13.44
2	2.88	0.23	14.87
3	3.79	0.31	12.61
4	4.26	0.35	12.77
5	5.21	0.40	15.02
6	5.70	0.45	16.12
7	6.72	0.51	14.61
8	6.52	0.53	16.55
9	5.84	0.45	14.56
10	4.23	0.32	24.42
11	5.90	0.41	16.93
12	9.17	0.52	19.38
13	7.05	0.53	17.31



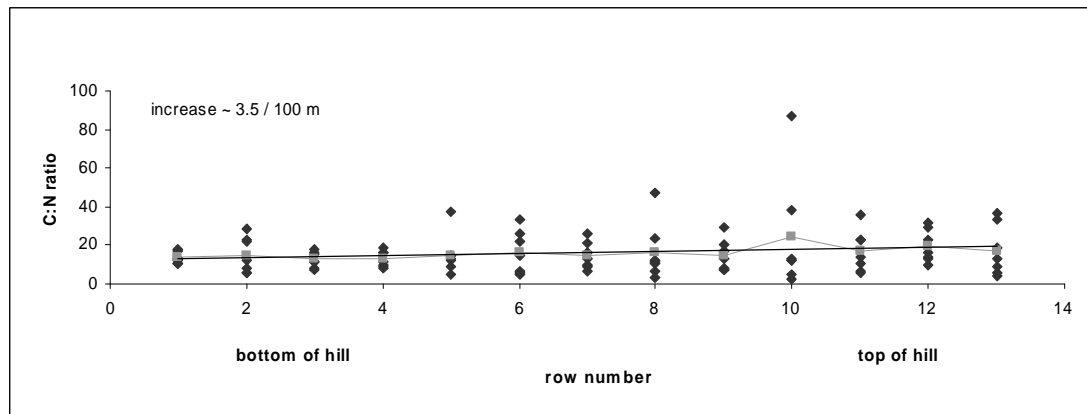


Figure 5.7 Carbon and nitrogen proportions and C:N ratios at each of the 91 sample sites (mean of the three layers for those sites where each horizon was analysed separately). The grey points and lines are the mean value per row and mean value trendline. The gradient (increase per 100m) is indicated for each variable.

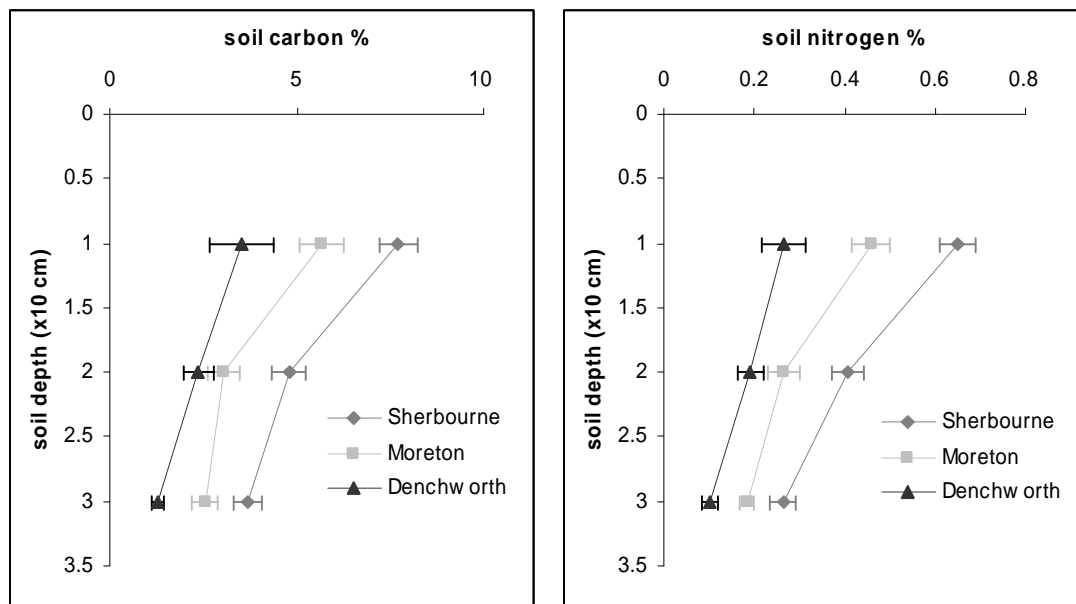
Looking at the soil nutrients individually for each soil and for the three horizons (Table 5.6, Figure 5.8), Sherbourne has the highest proportion of carbon and nitrogen and Denchworth the smallest. For all three soils there is a decrease with increasing soil depth, from around 8% to 4% for carbon and 0.6% to 0.3% for nitrogen in the case of Sherbourne.

Table 5.6: Nutrient content by soil series and depth.

	Sherbourne	Moreton	Denchworth
Carbon %			
0-10 cm	7.72	5.65	3.54
10-20 cm	4.80	3.04	2.37
20-30 cm	3.69	2.55	1.29
Nitrogen %			
0-10 cm	0.65	0.46	0.26
10-20 cm	0.41	0.27	0.19
20-30 cm	0.26	0.18	0.10
Calcium Mg/kg			
0-10 cm	7973.52	8942.50	3137.58
10-20 cm	10218.30	8523.25	2176.91
20-30 cm	20414.59	21617.00	3663.16
Potassium Mg/kg			
0-10 cm	355.46	389.33	278.23
10-20 cm	188.34	199.44	146.22
20-30 cm	136.57	140.79	123.00
Magnesium Mg.kg			
0-10 cm	265.06	255.39	170.47
10-20 cm	185.41	138.13	106.30
20-30 cm	180.75	186.54	96.69
Phosphorus Mg/kg			
0-10 cm	9.32	124.56	64.03
10-20 cm	5.59	66.28	58.63
20-30 cm	21.51	118.87	229.74

Calcium content markedly increases with depth for the less clay-rich soils, Moreton and Sherbourne but varies very little for Denchworth, which also has much lower proportions (about 3000 mg/kg compared with an average of 13,000 mg/kg for the other two soil types). For potassium, all three soil types show a significant decrease between the first two horizons and then a smaller decrease between the second and third; overall from > 300 mg/kg to < 150 mg/kg. Soil magnesium also appears to decrease with depth, though this is much less marked, and in the case of Moreton, the lowest horizon has a larger amount than the second horizon. Here again the Denchworth soil has significantly less magnesium than the other two soil types: ~120 mg/kg and ~200 mg/kg, respectively. It is unclear whether there is a trend with increasing soil depth for phosphorus content, but Denchworth and Moreton fluctuate much more than Sherbourne.

Generally, it appears that the Denchworth soil is the least fertile, certainly in terms of carbon, nitrogen, calcium, potassium and magnesium content.



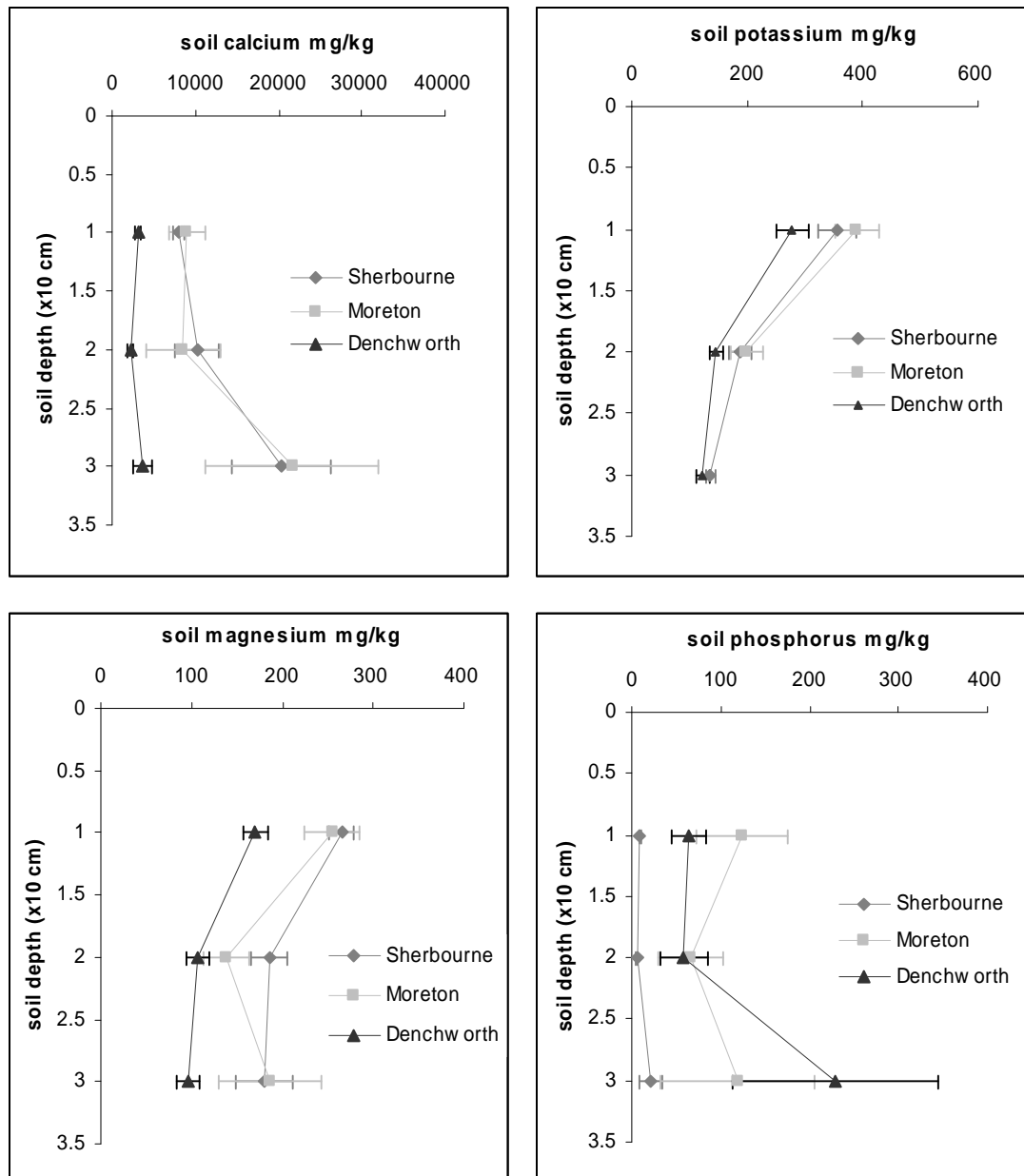


Figure 5.8 Soil nutrients by soil type and depth.

Examination of nutrient ratios: carbon: nitrogen, carbon:phosphorus and nitrogen: phosphorus indicated that Sherbourne and Moreton were similar for C:N, which generally increased with depth while that for Denchworth decreased with depth, and that Sherbourne had much higher ratios of C:P and N:P than the Denchworth and Moreton soils (Table 5.7, Figure 5.9).

Table 5.7: Soil nutrient ratios by series and depth.

	Sherbourne	Moreton	Denchworth
C:N			
0-10 cm	11.8748	12.3552	13.3975
10-20 cm	11.8239	11.4575	12.4061
20-30 cm	14.0112	13.8503	12.6721
C:P			
0-10 cm	0.8290	0.0454	0.0553
10-20 cm	0.8592	0.0458	0.0404
20-30 cm	0.1717	0.0214	0.0056
N:P			
0-10 cm	0.0698	0.0037	0.0041
10-20 cm	0.0727	0.0040	0.0033
20-30 cm	0.0123	0.0015	0.0004

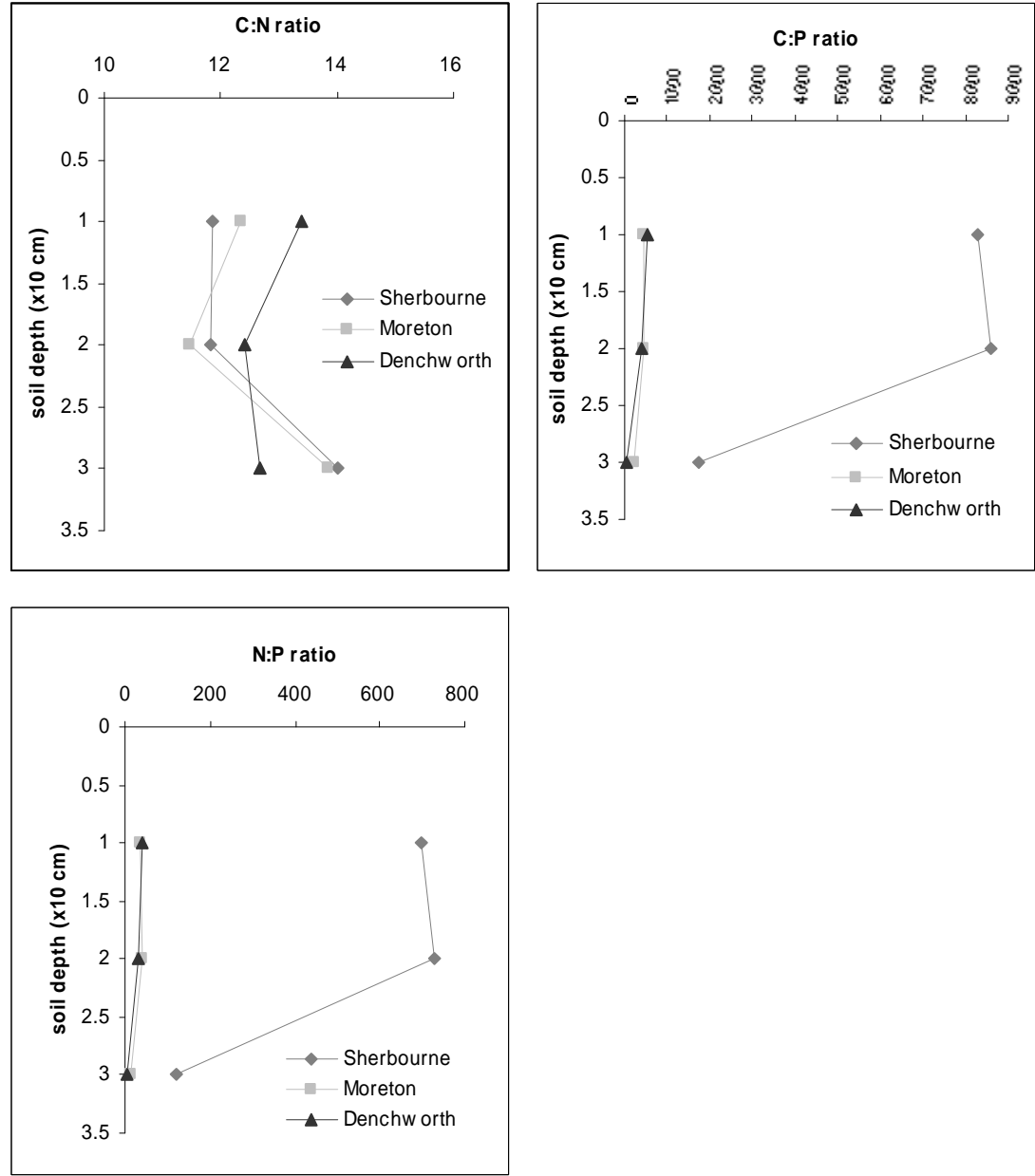


Figure 5.9: Soil nutrient ratios by soil and depth.

Carbon stock calculations

Using the mean plot soil carbon value of 6%, which equates to g/g, and the mean bulk density value of $0.935 \text{ g/m}^3 (\pm 0.02)$, this gives $935 \text{ kg/m}^3 \times 0.06 \times 0.1 \text{ m}$ (for top 10 cm soil section), which gives 5.61 kg/m^2 , or 56 Mg/ha^{-1} . For the second 10 cm of soil (10-20 cm depth) the calculation is: $935 \times 0.037 \times 0.1 = 3.46 \text{ kg/m}^2$, or 35 Mg/ha^{-1} . For the 20-30 cm depth the calculation is: $935 \times 0.027 \times 0.1 \text{ m} = 2.52 \text{ kg/m}^2$, or 25 Mg/ha^{-1} . The estimate for the total amount of soil carbon in the plot is therefore 116 Mg/ha^{-1} ; which equates to 139 MgC/ha^{-1} . There is an increasing trend with slope for MgC/ha^{-1} (Figure 5.10).

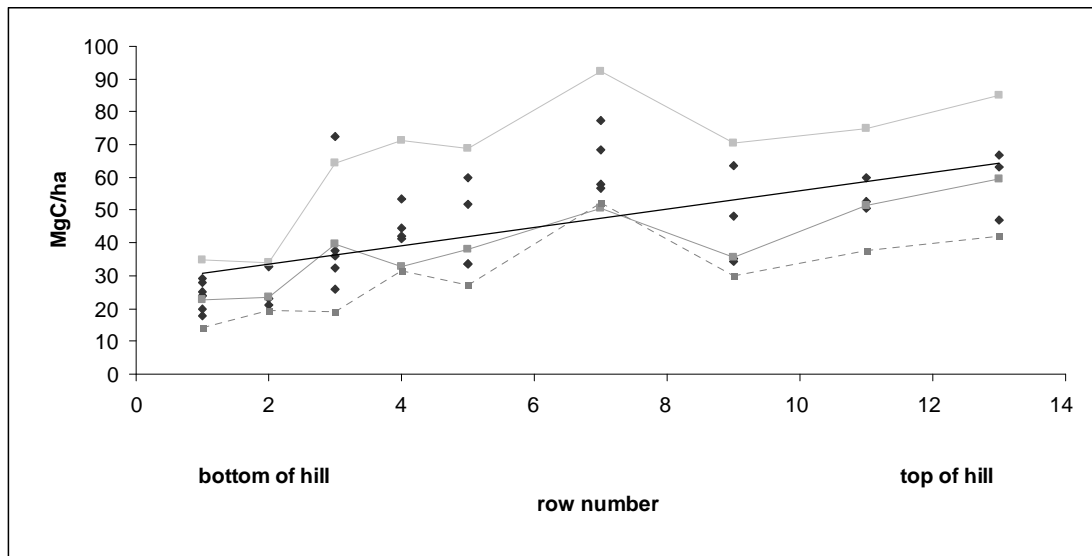


Figure 5.10: The relationship between carbon stocks and slope in the plot. The straight line is the overall trend for the mean of the three soil depths, the light grey line represents the top 10 cm of soil, the dark grey line the mid 10 cm and the dotted grey line the lower 10 cm of the soil profile.

A complete carbon budget for the plot (including soil carbon, coarse woody debris, and tree biomass) is at the end of the report (Section 8).

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6 Ground flora survey

The dominant ground flora species of the Wytham CTFS plot is *Mercurialis perennis*, which varies in frequency and abundance across the plot and throughout the year. It reproduces primarily vegetatively and is one of the earliest spring emergents (shoots appear in February). In some areas in the plot its cover is reduced as *Endymion non-scripta* dominates – this is usually in places where the soil is wetter. Generally in the Wytham CTFS plot, the ground flora is an *M. perennis* - *E. non-scripta* community, however, in one part of the lower end of the plot, there is a distinct *Allium ursinum* sub-community (Figure 6.1), while higher up the hill sedges and grasses characterise the ground flora in a few places. *E. non-scripta*, *A. ursinum* and other spring flowering species die back during the summer and *M. perennis* once more becomes the dominant or only species in most areas.



Figure 6.1: *Allium ursinum* sub-community; *M. perennis* at the bottom of the photograph.

Survey methods

The ground flora investigation was made of three parts: a) the installation and surveying of a network of permanent quadrats to provide both a current description of species composition

and a way of monitoring changes in ground flora composition over time; b) a description of the large community zones and the production of a phytogeographic map of the plot, and; c) a monthly sampling of leaf area at key locations, to provide an indication of productivity in the main community zones throughout the growing season. The installation and initial survey of the permanent quadrats took place in the first two weeks of May, and thus should be repeated during this period in subsequent surveys.

Ground flora quadrats

Using the 50 m interval grid (as with the soil sampling), 2 m x 2 m quadrats were laid out at the 91 sites and permanently marked with numbered pvc canes (Figure 6.2). Using a compass, the axes of the quadrats were laid out N-S and W-E. Within each quadrat, temporarily delimited by biodegradable tape, each species was identified and its percentage cover estimated (using the categories $\leq 1\%$, 2%, 5%, and then in increments of 5% up to 100% cover).

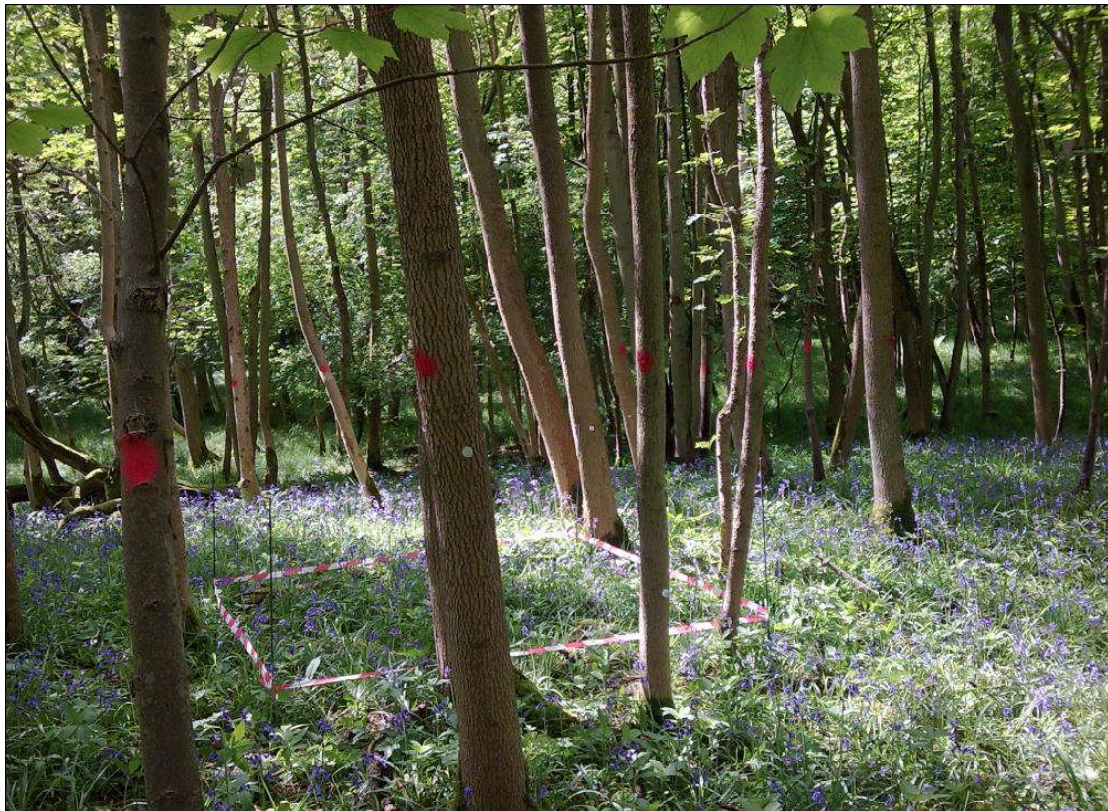


Figure 6.2: 2 m x 2 m permanent ground flora quadrat

Phytogeographic map

The broad spatial variation in ground flora was described according to Rodwell's (1991) classification, with the presence or absence of key species used to make distinctions between sub-communities where possible. Ranges of community types were established and mapped to illustrate this spatial variability (Figure 6.3).

Key to figure:

Broad community types:

Mercurialis perennis & *Endymion non-scripta* dominated; also *Dryopteris filix-mas* multiple *Gramineae* spp. and *Cyperaceae* spp., and other rarer flora.

Gramineae and Cyperaceae dominated, *Carex pendula* always present, *Mercurialis perennis* present.

Allium ursinum dominated.

Urtica dioica, *Pteridium aquilinum* and Gramineae/Cyperaceae dominated.

Needle debris layer – little ground cover. *Urtica dioica* dominated.

Sub-categories:

1a Sparse area, maintaining composition

1b *Endymion non-scripta* absent

1c including *Urtica dioica* and *Pteridium aquilinum*

1d *Endymion non-scripta* absent and including *Urtica dioica* and *Pteridium aquilinum*

1e *Endymion non-scripta* dominated

2a including *Urtica dioica* and *Pteridium aquilinum*

2b *Mercurialis perennis* absent

2c *Mercurialis perennis* absent; also sparse

3 *Allium ursinum* sub-community

4a *Pteridium aquilinum* absent

4b *Mercurialis perennis* present

——— paths

----- boundary of community/sub-community (otherwise delimited by a change in slope, a path, or where there is an indistinct boundary, by no marking)

● line of significant change in slope

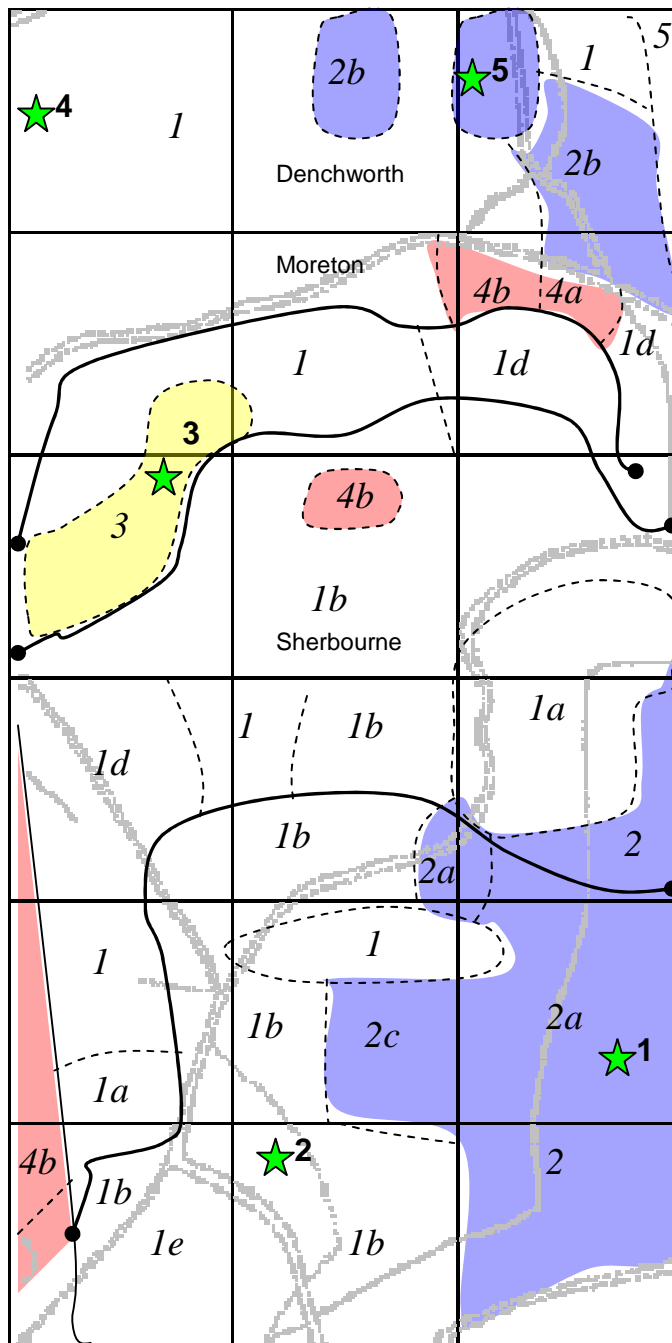


Figure 6.3: Phytogeographic map of the 18 ha plot including distribution of soil types. The green asterisks denote the locations of the monthly leaf collections (see 'Leaf-area phenology', below).

Leaf-area phenology

To look at seasonal changes in leaf area (and thus productivity) across various ground flora communities leaves were collected on a monthly basis during the growing season (April-September) from five sites. These sites (see Fig. 6.3) were one each at the top and bottom of the hill for two communities: *M. perennis* - *E. non-scripta* and *Gramineae* and *Cyperaceae* dominated (grass and sedge – typical areas had *Poa trivialis*, *Brachypodium sylvaticum*, and *Deschampsia cespitosa* all present). The fifth site was that of the *A. ursinum* sub-community. At each site, leaves from five quadrats of 0.5 m x 0.5 m were collected: 25 quadrats per month. As this was destructive sampling, with all leaves within the quadrat removed (see Figure 6.4), quadrats in the immediate vicinity to those sampled the previous months were sampled. The first batch of leaves were scanned (using Scion Image™) (Fig. 6.4) and then dry weighed (at 60°C over several days) in order to derive a relationship between leaf area and weight which could then be applied to the subsequent batches of leaves to give a monthly calculation of leaf area.



Figure 6.4: Collecting and scanning ground flora leaves.

Results

Ground flora quadrats

32 species were recorded in the permanent 2 m x 2 m ground flora quadrats (Table 6.1), and the three most common mosses identified.

Table 6.1: Ground flora species

Latin name	English name
<i>Alliaria petiolata</i>	Garlic mustard/ Jack-By-The-Hedge
<i>Allium ursinum</i>	Ramsons
<i>Angelica sylvestris</i>	Wood angelica
<i>Arum maculatum</i>	Lords and Ladies
<i>Brachypodium sylvaticum</i>	False brome/Slender false brome
<i>Eurynchium praelogum</i> / <i>Brachythecium rutabulum</i>	Moss – there are many more species; these are the most common
<i>Plagiomnium undulatum</i>	
<i>Carex pendula</i>	Weeping sedge
<i>Carex sylvatica</i>	Wood sedge
<i>Circaea lutetiana</i>	Enchanter's Nightshade
<i>Conopodium majus</i>	Pignut
<i>Convolvulus arvensis</i>	Bindweed
<i>Deschampsia cespitosa</i>	Tufted hair grass
<i>Dryopteris filix-mas</i>	Fern
<i>Endymion non-scripta</i>	Bluebell
<i>Euphorbia amygdaloides</i>	Wood spurge
<i>Galium aparine</i>	Cleavers/ Goosegrass
<i>Geum urbanum</i>	Wood avens
<i>Glechoma hederacea</i>	Ground ivy
<i>Lamium galeobdolon</i>	Yellow archangel
<i>Mercurialis perennis</i>	Dog's mercury
<i>Orchis mascula</i>	Early purple orchid
<i>Oxalis acetosella</i>	Wood sorrel
<i>Paris quadrifolia</i>	Herb paris
<i>Poa trivialis</i>	Rough meadow grass
<i>Primula vulgaris</i>	Primrose
<i>Pteridium aquilinum</i>	Bracken
<i>Ranunculus ficaria</i>	Lesser celandine
<i>Ranunculus repens</i>	Creeping buttercup
<i>Rubus fruticosus</i>	Bramble
<i>Rumex acetosa</i>	Narrow-leaved dock
<i>Taraxacum officinale</i>	Dandelion
<i>Urtica dioica</i>	Nettle
<i>Viola riviniana/reichenbachiana</i>	Common dog violet/ Early dog violet

The most frequently recorded species were: *M. perennis*, *B. sylvaticum*, *P. trivialis*, *C. lutetiana*, *E. non-scripta* and *A. maculatum*, which were present in twenty or more quadrats (Table 6.2, Figure 6.5).

Table 6.2: Frequency (number of quadrats where recorded) and coverage (%) of the most common species.

	frequency	% mean cover
<i>Mercurialis perennis</i>	79	32.78
<i>Brachypodium sylvaticum</i>	55	2.84
<i>Poa trivialis</i>	53	9.29
<i>Circaea lutetiana</i>	39	1.40
<i>Endymion non-scripta</i>	37	5.44
<i>Rubus fruticosus</i>	34	0.66
<i>Arum maculatum</i>	31	0.54
<i>deschampsia cespitosa</i>	19	1.84
<i>Dryopteris filix-mas</i>	16	0.25
<i>Urtica dioica</i>	16	2.33
<i>Galium aparine</i>	13	0.77
<i>Geum urbanum</i>	13	0.32
<i>Pteridium aquilinum</i>	10	0.41
<i>Carex sylvatica</i>	10	0.14
<i>Ranunculus ficaria</i>	8	0.34
<i>Carex pendula</i>	7	0.56
<i>Allium ursinum</i>	6	1.22

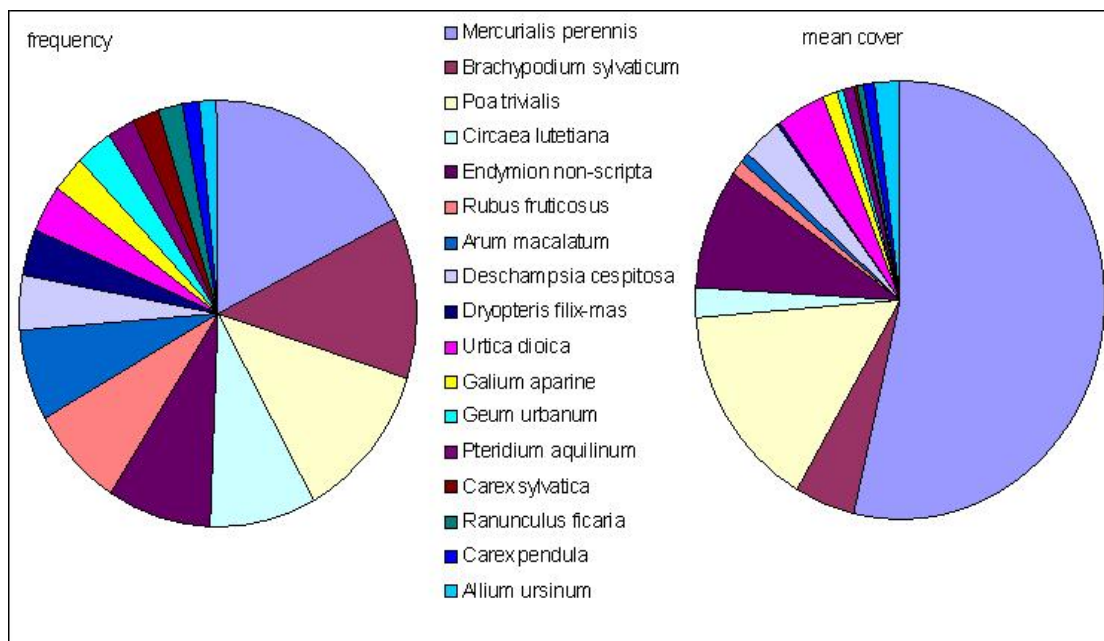


Figure 6.5: Frequency of occurrence and proportional coverage of the most common species.

The two indicator species of this type of woodland, *M.perennis* and *E. non-scripta* occur together widely throughout the plot, with dominance alternating, probably according to soil wetness. Figure 6.6 illustrates this relationship: nowhere do they co-occur with more than 30 or 40% coverage for both.

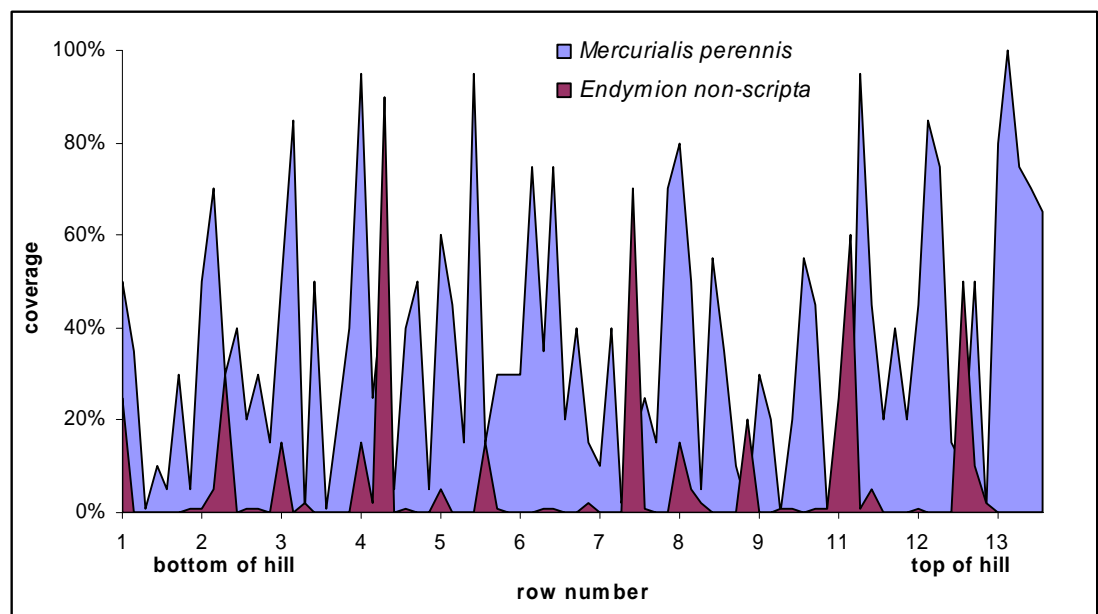


Figure 6.6: Coverage of *M. perennis* and *E. non-scripta* by quadrat.

Leaf area phenology

The initial leaf collection gave a range of area and weight values and Specific Leaf Areas values (SLA), (Table 6.3) the lowest of which was for the *Gramineae* and *Cyperaceae*, and the highest for the *A. ursinum*.

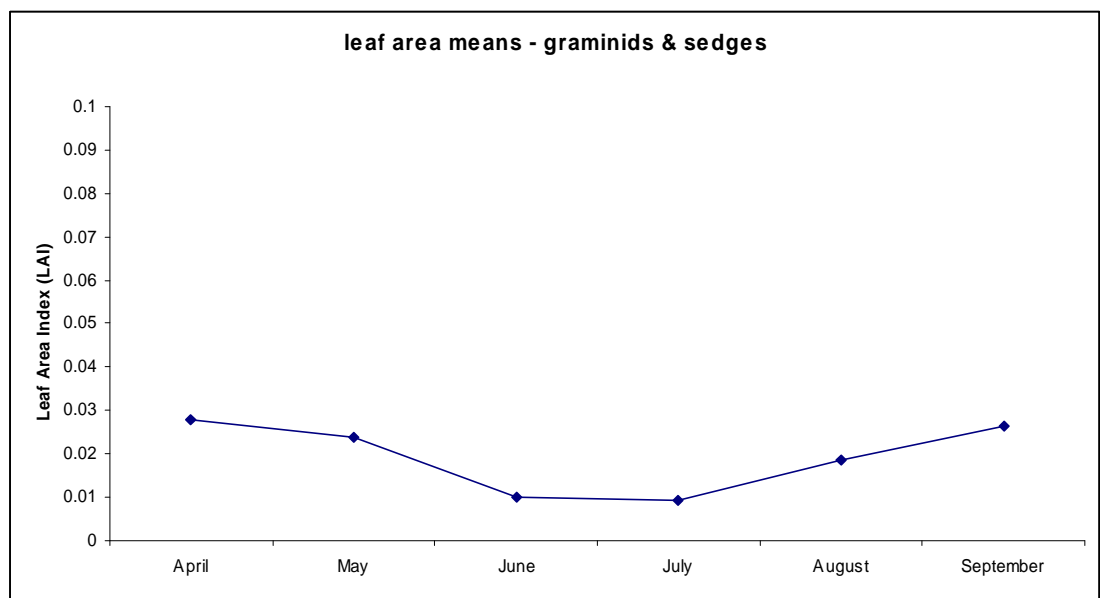
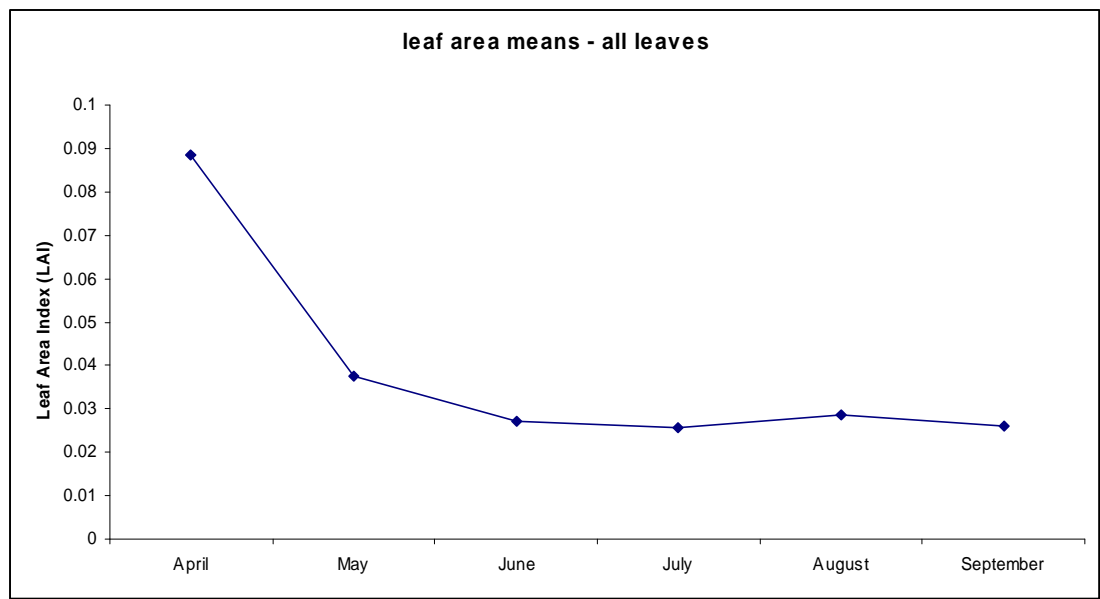
Table 6.3: Total area, weights and SLA (from area/weight) for all ground flora collected.

	Area (cm ²)	Weight (g)	SLA
<i>M. perennis</i>	8076.36	23.00	351.15
<i>M.perennis</i> + <i>C. lutetiana</i>	12981.36	39.19	331.24
<i>M. perennis</i> + <i>E. non-scripta</i>	13801.48	39.35	350.74
<i>P. filix-mas</i>	511.78	1.67	306.46
<i>M. perennis</i> + <i>E. non-scripta</i> + <i>C. lutetiana</i>	11798.79	25.41	464.34
Combined, excl. <i>A. ursinum</i> , grasses & sedges	2748.51	7.81	352.14
<i>A. ursinum</i>	18941.80	31.08	609.45
<i>Gramineae</i> + <i>Cyperaceae</i>	1109.31	5.52	200.96

Using these initial SLA values, the monthly leaf areas were calculated for each group for each month (Table 6.4, Figure 6.7). The peak of leaf area is in the spring (April), before the canopy is closed, and for all ground flora types this decreases from May onwards (*F. excelsior* is in full leaf from this time). In late summer (August), grass and sedge species begin to increase again, outcompeting the forb species. During this late summer period, the forb species leaf area remains fairly constant, and then begins to decrease again in autumn (September). The graminids and sedges will maintain leaf area throughout the autumn and winter months, while the rest of the ground flora will gradually decline before the large sudden increase in early spring.

Table 6.4: Monthly leaf areas (cm²), by group.

	all leaves	<i>Gram. & Cyper.</i>	forbs
April	3544.704	1109.3	4031.78
May	1504.826	958.80	1868.85
June	1084.894511	394.92	1636.88
July	1030.571135	376.27	1423.15
August	1152.215088	750.31	1393.36
September	1045.024092	1053.24	1041.74



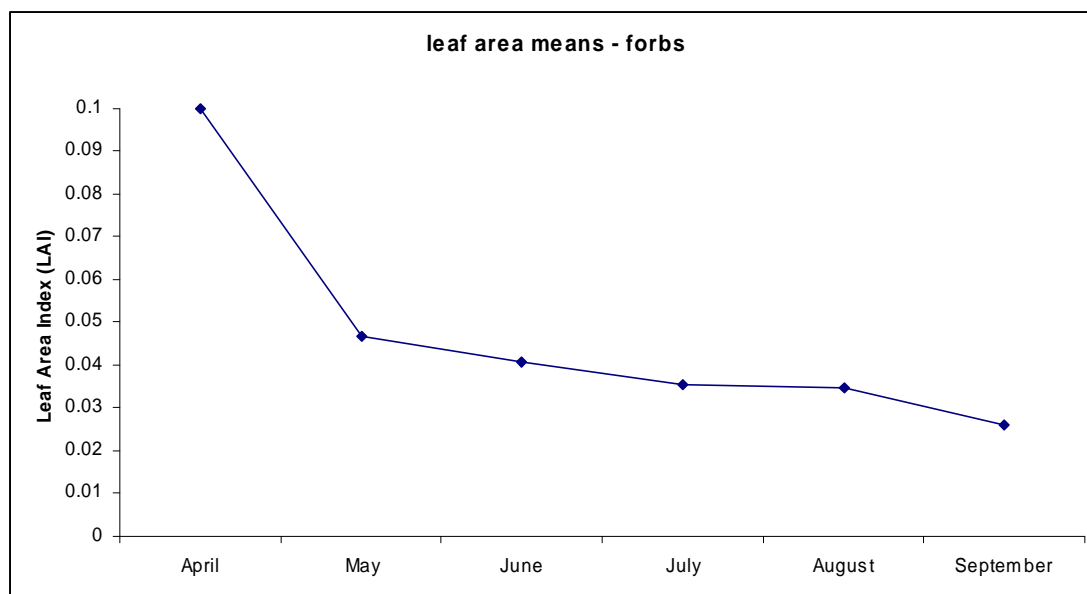


Figure 6.7: Monthly changes in leaf area, by group (as area of leaf per area of ground).

Rodwell, J.S. (Ed). 1991. *British Plant Communities. Volume 1: Woodlands and Scrub*. Cambridge University Press.

7. Dendrometer bands

Dendrometer bands are sensitive enough to enable the accurate measurement of seasonal tree growth and also changes in diameter at much higher temporal resolution, so, for example, contraction and expansion during the diurnal/nocturnal cycle can be observed.

In the plot the dendrometer bands will be used to investigate the effect of possible differences in soil nutrients and slope on tree growth, in terms of variability by species and size class.

Sampling Design

Dendrometer bands were installed at two sites in the plot, at the north (bottom of the slope) and south (top of the slope) ends. The sites are of similar size and are situated in areas of similar forest structure and topography; the site at the bottom of the hill is located primarily in Plo2, the uphill site spreads across several plots (14, 15, 16 & 17) (Figure 7.1). In each site 150 bands were installed.

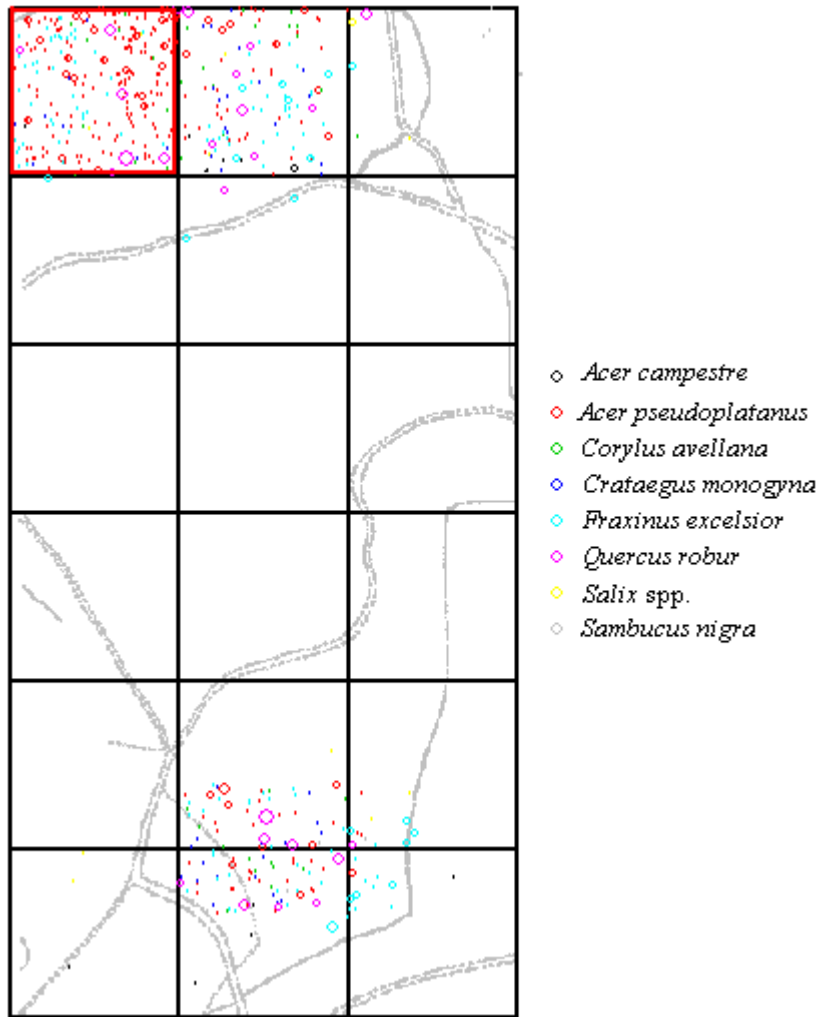


Figure 7.1: Location of new dendrometer band sites. (Symbol size is proportional to dbh – approximately ten times actual size). Existing dendrometer bands are installed as indicated (red outline) in the carbon cycle studies plot.

Each group of 150 was a stratified sample by species and size (dbh class). The five major species (*Acer pseudoplatanus*, *Fraxinus excelsior*, *Corylus avellana*, *Crataegus monogyna*, *Quercus robur*) were sampled nine times in each of five sizes classes (0.5-100mm, 100-200 mm, 200-300 mm, 300-400 mm, 400+ mm). *Corylus avellana* and *Crataegus monogyna* only had sufficient stems in the 0.5-100 mm and 100-200 mm categories, and *Quercus robur* only in the 400+ mm category, so were only sampled in these categories. The remaining 15 stems in each sample were made up of five stems of *Acer campestre*, *Salix* spp. and *Sambucus nigra*. These three species were sampled without regard to size, and were included to provide a broader sample of tree species - no other species had a significant upslope and downslope presence; they either had too few individuals or were not evenly spatially distributed.

Field Installation

For band installation, we followed the procedure of Keeland and Young (2007), with some local modifications (for example, polypropelene packing tape was used instead of stainless steel bands as it is easier to work), as follows:

A length of packing tape was folded and clamped at one end to make a small loop and the clamped tape then held around the tree to measure how much tape would be required (Figure 7.2a,b) to leave a gap of approximately 150 mm between the ends. The tape was then cut, leaving a length of around 100 mm at the new end. The folded edges of the loops were trimmed to make it easier to affix the spring, and the band was then held around the tree and the spring hooked on (Figure 7.2c) after which it could be corrected so that it sits perpendicular to the stem (Figure 7.2d). After installation the bands were left to settle for a few months before measurements began. Notches were then made with a sharp knife at the point where the two tails of the band overlap (Figure 7.2e). When measurements are taken in the future, a Vernier calliper will be used to measure the distance between the notch and the tail of the band. Dbh will also be re-measured at this time and the distance between this point of measurement and the dendrometer band also recorded.



a



b



c



d



e

Figure 7.2 a) making and clamping a loop, b) sizing the dendrometer band *in situ*, c) attaching the spring, d) ensuring correct alignment, e) cutting the notch after several months.

Keeland and Young, 2007 Keeland, B.D., Young, P.J., 2007. Construction and installation of dendrometer bands for periodic tree-growth measurement.
<http://www.nwrc.usgs.gov/Dendrometer/>.

8. Carbon stocks

The above-ground (standing) biomass was calculated using species specific formulae for *A. pseudoplatanus*, *F. excelsior* and *Q. robur* (see Bunce, 1968) derived from a similar woodland, and for the remaining species a mean of the equation constant and coefficients were used, and the standard C% = dry mass*0.5. The totals and hectare means for each species were calculated (Table 8.1).

Table 8.1: Carbon content (kg) by species, totals and hectare means, and contribution to total carbon content.

	kg C	kgC/ha	total carbon %
<i>A. campestre</i>	11615.40	645.30	0.67
<i>A. pseudoplatanus</i>	763481.03	42415.61	44.025
<i>Betula</i> spp.	10073.68	559.65	0.581
<i>C. betula</i>	57.50	3.19	0.003
<i>C. sativa</i>	36.81	2.05	0.002
<i>C. avellana</i>	11472.92	637.38	0.662
<i>C. monogyna</i>	10368.19	576.01	0.598
<i>E. europaeus</i>	129.07	7.17	0.007
<i>F. sylvatica</i>	33210.94	1845.05	1.915
<i>F. alnus</i>	62.88	3.49	0.004
<i>F. excelsior</i>	322806.00	17933.67	18.614
<i>I. aquifolium</i>	75.70	4.21	0.004
<i>L. decidua</i>	62866.68	3492.59	3.625
<i>P. abies</i>	4986.49	277.03	0.288
<i>P. sylvestris</i>	914.28	50.79	0.053
<i>P. avium</i>	77.16	4.29	0.004
<i>P. spinosa</i>	126.82	7.05	0.007
<i>P. menziesii</i>	476.84	26.49	0.028
<i>Q. robur</i>	500316.61	27795.37	28.85
<i>Salix</i> spp.	4682.02	260.11	0.27
<i>S. nigra</i>	1288.01	71.56	0.074
<i>T. baccata</i>	3.27	0.18	0.0002
<i>T. europaea</i>	4063.87	225.77	0.234
Total Mg	1743.19	96.84	

Total plot carbon stocks

In order to calculate a carbon budget for the plot, soil, above-ground biomass and woody debris stocks need to be combined. The ratio of biomass C/soil C is 0.7. Below-ground (root) biomass is probably about 20% of the above-ground biomass, and can be included in the total carbon budget (Table 8.2).

Table 8.2: Carbon stocks (MgC/ha^{-1}) for the three measured variables, and estimated root biomass.

	Carbon stock value
Woody debris	3.57 MgC/ha^{-1}
Above-ground biomass (trees)	96.8 MgC/ha^{-1}
Estimated below-ground biomass	$19.36 \text{ MgC/ha}^{-1}$
Soil	139 MgC/ha^{-1}
Total	$258.75 \text{ MgC/ha}^{-1}$

Bunce, R. G. H. 1968. Biomass and Production of Trees in a Mixed Deciduous Woodland: I. Girth and Height as Parameters for the Estimation of Tree Dry Weight. *Journal of Ecology*, **56**, pp. 759-775.

9 Flux tower measurements

The Wytham Woods flux tower

Forests around the globe partially offset human emissions by absorbing or sequestering CO₂ through photosynthesis. However, forests also release CO₂ through respiration: net sequestration of carbon by forests occurs when rates of photosynthesis exceed respiration. The balance of these two processes is influenced by a number of factors such as stand age, season, phenology and weather conditions.

The Wytham flux tower, installed and maintained by CEH, and funded by the Natural Environment Research Council (NERC), is one of the few in the UK. Measurements of the exchange (or flux) of CO₂ between the atmosphere and the vegetation below allow analysis of daily and monthly variations caused by changes in the weather and ecological processes. Fluxes also provide a robust estimate of whether the forest is acting as a source or sink of carbon at annual timescales. Although not part of the SIGEO plot project, this section is included for interest and to provide further information on the Wytham Woods environment.

Flux measurements

Air flows consist of numerous eddies (turbulence) of varying size and strength. Eddies essentially move parcels of air of varying humidity, temperature and gas concentration either towards or away from the ground at different speeds (Figure 9.1). A sonic anemometer, installed on the flux tower, emits ultrasonic pulses to measure wind velocities and virtual temperature, and from these the net exchange or 'flux' of these air parcels and their associated characteristics, such as CO₂ concentration measured by an infrared gas analyser (IRGA), are calculated. The assembled flux equipment measures the covariance (how two variables change together) between fluctuations in vertical wind velocity (in the form of eddies) and the mixing ratio of trace gases such as CO₂. This is known as eddy covariance.

When assessing CO₂ fluxes over forests, negative flux values indicate a net loss of CO₂ from the atmosphere and a gain by the surface (i.e., a net uptake of CO₂ by plants during photosynthesis). When respiration rates are greater than photosynthesis, the covariance values become positive, representing a net loss of CO₂ from the underlying vegetation to the atmosphere. The area of forest over which fluxes are measured by the eddy covariance equipment, the flux footprint, is what the flux tower can 'see' upwind of its location. Generally, the higher the equipment is placed, the greater its field of vision, or 'fetch'. The footprint size is dynamic, varying with wind direction and strength,

thermal stability and ecosystem characteristics, such as canopy height and roughness. At Wytham, the 25 m tower has an estimated fetch of around 200 to 800 m, depending upon the local weather conditions.

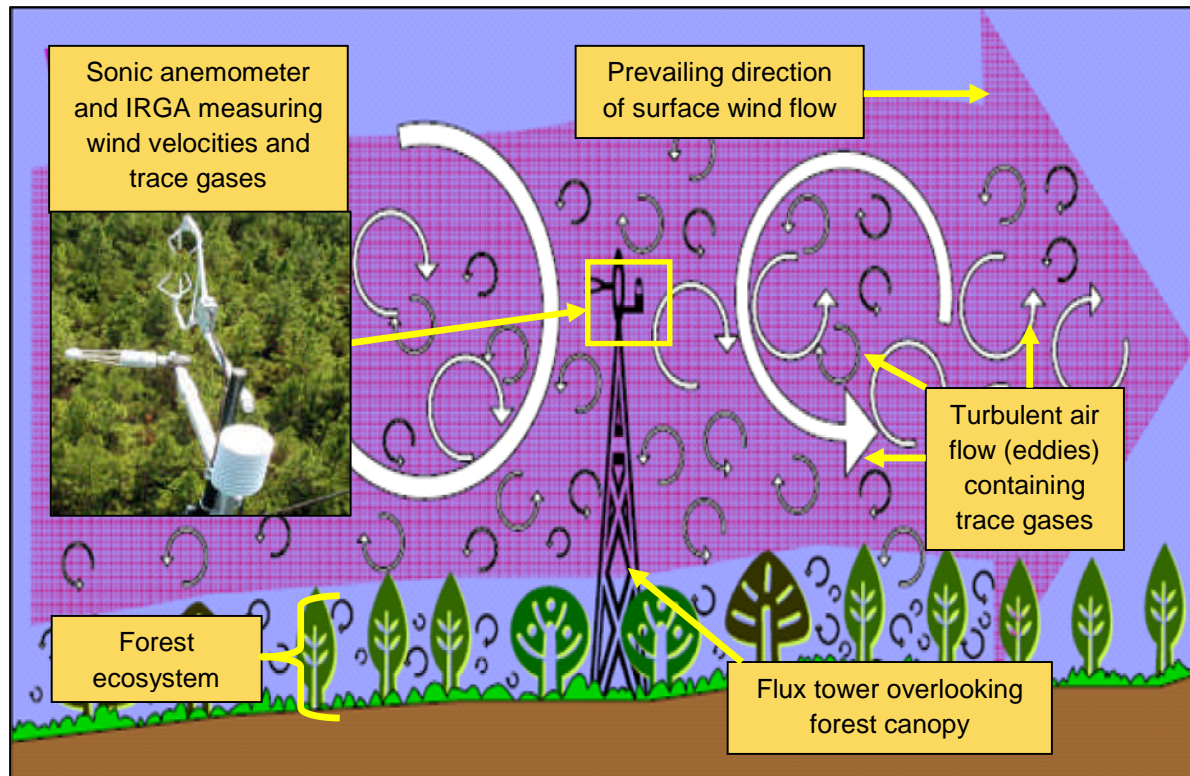


Figure 9.1: Summary of setup and principles underlying eddy covariance. (Adapted from Burba and Anderson, 2007).

Flux data analysis

Analyses of two years of flux data recorded between May 2007 and April 2009 show how the fluxes of CO_2 vary with both season and time of day (Figure 9.2). Over the two-year study period there were high sequestration rates of carbon dioxide during summer months when photosynthesis exceeded respiration. During such periods, the forest can be considered a carbon sink (Figure 9.3). However, through the winter months Wytham Woods typically turned into a carbon source, in the form of CO_2 , as respiration became the dominant process.

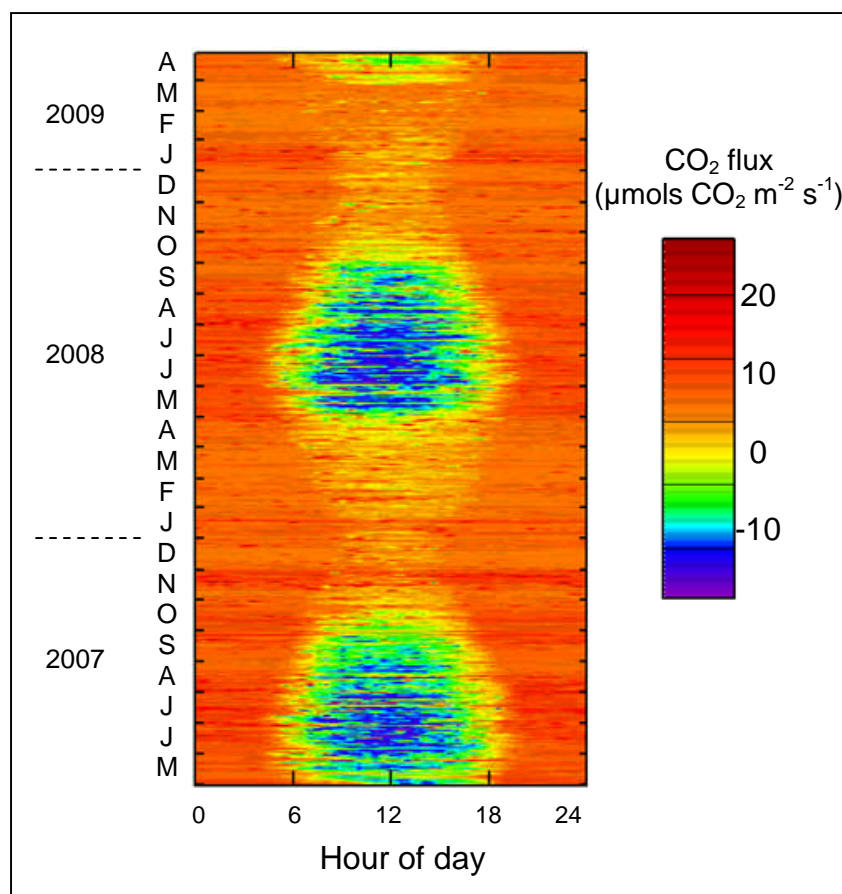


Figure 9.2: Variations in CO₂ fluxes during time of day over the study period. The dark blue areas represent maximum CO₂ uptake by the vegetation of Wytham Woods.

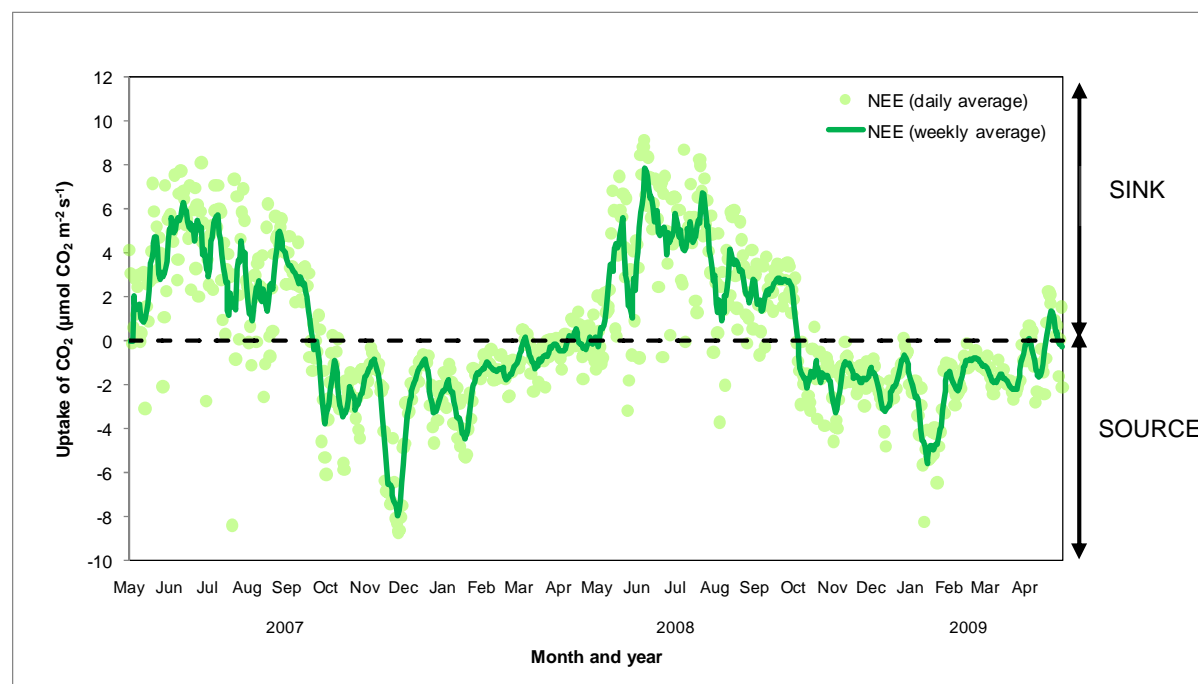


Figure 9.3: Uptake of CO₂ calculated from net ecosystem exchange (NEE) between May 2007 and April 2009.

The partitioning of the flux data into gross primary productivity (GPP), respiration and NEE (the difference between GPP and respiration) demonstrates the effect of seasonality upon photosynthesis and respiration (Figure 9.4), illustrating the net fluxes of carbon between the atmosphere and the forest. Most seasons show positive values of NEE, suggesting that Wytham Woods are a substantial carbon sink. During 2008 the forest sequestered in total an estimated 2.7 t C ha^{-1} (Figure 9.5): this estimate compares well with other studies of broadleaved deciduous woodland in the UK (Broadmeadow & Matthews, 2003; Fenn *et al.*, 2009).

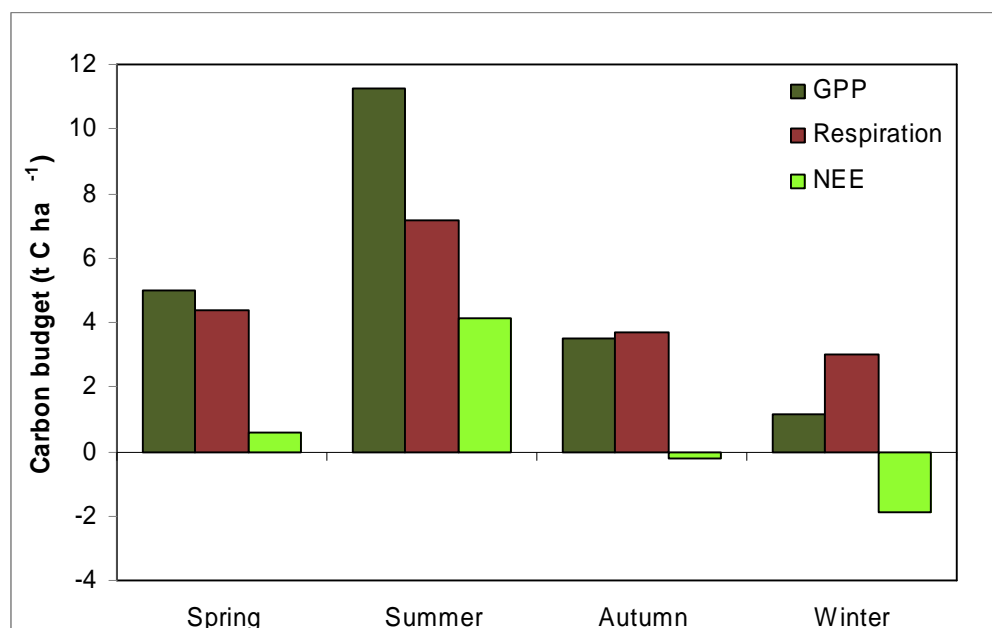


Figure 9.4: Seasonal carbon budget for 2008.

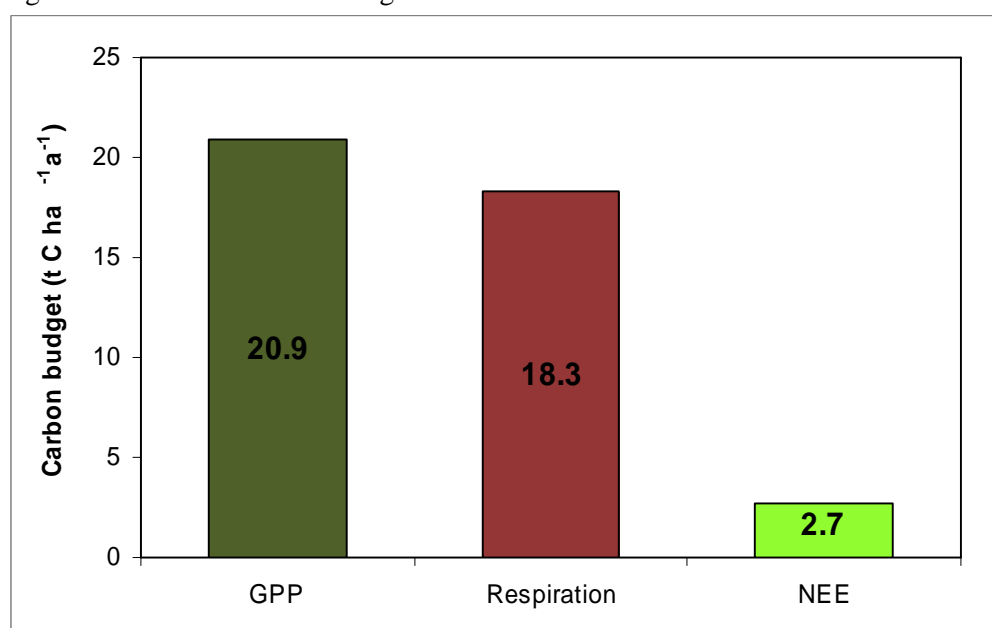


Figure 9.5: Annual carbon budget for 2008.

The carbon sink value of Wytham Woods has important implications for the protection of semi natural woodland around the UK, while on a more local scale, the flux data suggest that Oxford University's ownership and management of Wytham Woods is offsetting approximately one sixth of the colleges' total CO₂ emissions.

References

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- Burba, G., and Anderson, D. (2007). *Introduction to Eddy Covariance method: general guidelines and conventional workflow*. LiCOR Biosciences, LiCOR Inc. Nebraska, USA.
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