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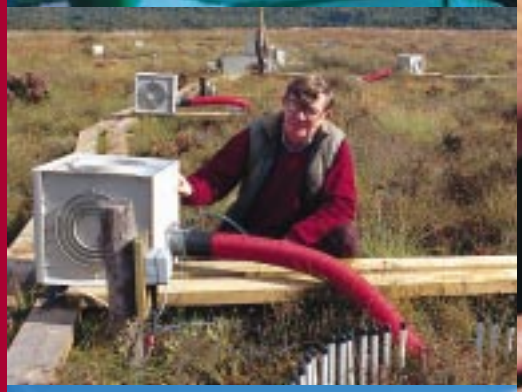

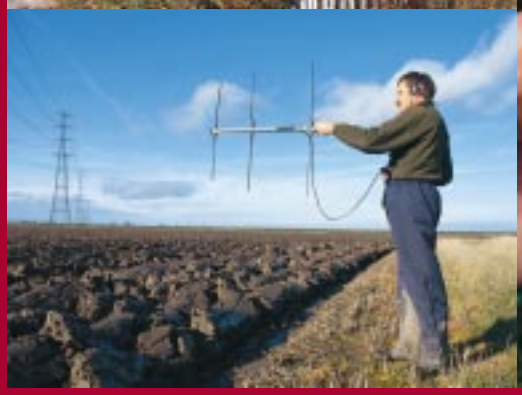

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Natural developments in a minimum intervention area in Buckholt Wood, part of the Cotswolds Commons and Beechwoods National Nature Reserve

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Preface

English Nature is grateful to Ed Mountford for the opportunity to include this report in its research report series. This should help to ensure that knowledge of the permanent vegetation transects at Buckholt Wood is maintained. The work was however done independently of English Nature and any views expressed are not necessarily those of English Nature and its staff.

Keith Kirby
English Nature

Acknowledgements

Anne Hargreaves assisted with the 2000 field recording and input the data onto computer spreadsheet. Graham Berry established part of the baseline and Malcolm Whitmore of English Nature was responsible for initiating the study. The recording in 2000 and this report form part of the NAT-MAN Project – Nature-based Management of Beech in Europe – financed by the European Community 5th Framework Programme.

Summary

- Changes in tree and shrub layers in an area of Buckholt Wood (Cotswold Commons and Beechwoods NNR) that was treated by minimum intervention were quantified by recording three permanent transects in 1992/4 and 2000.
- The area had clayey soils over limestone and included a short plateau and steeply sloping bank beneath. The stand had been mostly left untreated since selective felling in 1947, 1957 or soon after. The canopy was dominated by beech with some ash, and the understorey by holly with some whitebeam, hawthorn and yew. Crab apple, dogwood, field maple, goat willow, guelder rose, hazel, pedunculate oak, sycamore, rowan and wych elm were minor species.
- The stand had inherited/developed a distinct stratification. An upper canopy layer at about 25m high contained a scatter of beech trees that had been retained during the 1947/57 felling. Between these a mass of post-felling regeneration had developed strongly. A later felling, probably around 1970, had removed a single large beech tree from one place, which was marked by a pocket of younger regeneration. The largest, most vigorous regenerants formed a lower canopy and sub-canopy layer at 10-15m high. This was dominated by beech, apart from on the upper plateau where ash remained important. Whitebeam remained occasional and mainly in the sub-canopy layer, whilst pedunculate oak and goat willow survived as rare components of these layers. The smaller regenerants were mainly beech, whitebeam, holly, hawthorn and yew, but they also included several minor species. These dominated the lowest strata which included: (i) numerous slow-grown, suppressed regenerants of most species; (ii) abundant stems of holly which formed a dense and developing low-layer mainly on sloping ground; (iii) a similar layer of yew but taller and more localised on parts of the upper steep-slopes; and (iv) a group of younger regeneration below the 20 year-old gap, mostly of suppressed ash, whitebeam, hawthorn and beech.
- The main features of stand change since the stand had regenerated were: (i) limited canopy disturbance; (ii) decreasing stem density; (iii) disproportional loss of small-sized stems and shade-intolerant species due to exclusion (ash, hazel, oak, dogwood, goat willow); (iv) increasing basal area; (v) disproportional growth of medium-large stems; (vi) disproportional survival of shade-tolerant species (beech, holly, whitebeam, hawthorn, and yew); and (vii) development of shade-tolerant shrubs in the understorey (holly and yew). These processes of undisturbed growth, stem exclusion, and understorey reinitiation had and will probably continue to lead towards an increasing dominance by shade-tolerant species, mainly beech and holly with lesser amounts of whitebeam and yew.
- The influence of site condition and past management, the occurrence of features associated with mature woodland, the patterns of stand development, and recommendations for research and monitoring are discussed.

Contents

1. Introduction

This report is based on a long-term monitoring scheme and is concerned with natural stand change in an area of mature beech woodland. It extends similar research carried out at other National Nature Reserves, including Dendles Wood (Mountford, Page & Peterken 2001), Langley Wood (Mountford, Peterken & Burton 1998), and Monks Wood (Mountford & Peterken 1998). These contribute to a national programme of studies on long-term change in minimum intervention, semi-natural woodland, which was initiated in the mid-1980s under the general supervision of Dr. George Peterken. In addition to the above sites this includes a range of mature, mixed woodlands, notably Lady Park Wood in the Lower Wye Valley, Denny Wood in the New Forest, the Black Wood of Rannoch on the shores of Loch Rannoch, Clairinsh Island in Loch Lomond, Craigellachie birchwood above Aviemore, and Wistman's Wood on Dartmoor (Peterken & Backmeroff 1988, Hall *et al* 1999).

At each of these sites, permanent transects or plots have been established where the performance of trees and shrubs can be monitored every decade or so. This will enhance our knowledge of natural woodland dynamics in Britain by providing detailed information on tree growth, mortality, regeneration and natural disturbance, and in turn help inform ecologists and policymakers interested in natural woodland and nature-based forestry. With this in mind a representative series of minimum intervention woodland reserves and a programme of long-term monitoring therein has been proposed (Mountford 2000, Peterken 2000).

2. Study area

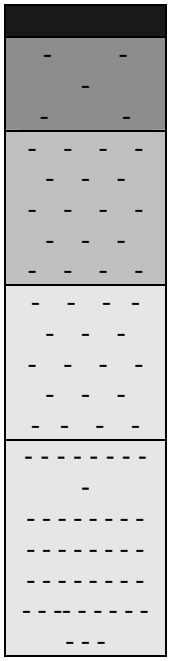
This study was carried out in part of Buckholt Wood (national grid reference SO 8913). This is an ancient semi-natural beechwood situated above Cranham village, north of Painswick and close to the Birdlip escarpment, in the west Cotswolds, Gloucestershire (Nature Conservancy Council 1990). It is part of the Cotswolds Commons and Beechwoods National Nature Reserve and a large Site of Special Scientific Interest (SSSI) that includes about 650ha of semi-natural beech woodland. The Birdlip-Painswick woods are regarded in the Nature Conservation Review as the finest beechwoods in the Cotswolds (Ratcliffe 1977) and are a candidate Special Area of Conservation under the EU Habitats Directive (English Nature 2000).

The wood occurs mainly on a plateau underlain by Jurassic limestone, with some sloping ground along incised valleys and on the adjacent scarp. The soils are mainly brown, shallow, well-drained, brashy, calcareous, fine loamy rendzinas with some deeper soils and some non-calcareous and calcareous clayey soils (Mackney *et al* 1983). An example profile from the study area is shown in Figure 1.

Most of the wood is beech high forest belonging to the W12 *Fagus sylvatica-Mercurialis perennis* community of the National Vegetation Classification (Rodwell 1991) and calcareous pedunculate oak-ash-beech stand types 8Ca/b of Peterken (1993). Single-stemmed beech (*Fagus sylvatica*) up to about 30m height account for most canopy trees, with gaps present where localised felling has occurred. In places individual trees or groups of ash *Fraxinus excelsior*, pedunculate oak *Quercus robur*, sycamore *Acer pseudoplatanus*, whitebeam *Sorbus aria*, wild cherry *Prunus avium*, and (near streams) alder *Alnus glutinosa* are encountered. The shrub layer is variable and includes crab apple *Malus sylvestris*,

dogwood *Cornus sanguinea*, elder *Sambucus nigra*, field maple *Acer campestre*, goat willow *Salix caprea*, guelder rose *Viburnum opulus*, hazel *Corylus avellana*, hawthorn *Crataegus monogyna*, rowan *Sorbus aucuparia*, spindle *Euonymus europeaus*, wych elm *Ulmus glabra*, and yew *Taxus baccata*.

Figure 1 Example profile from the study area where the soil is a calcareous, clayey rendzina over clay and Jurassic limestone



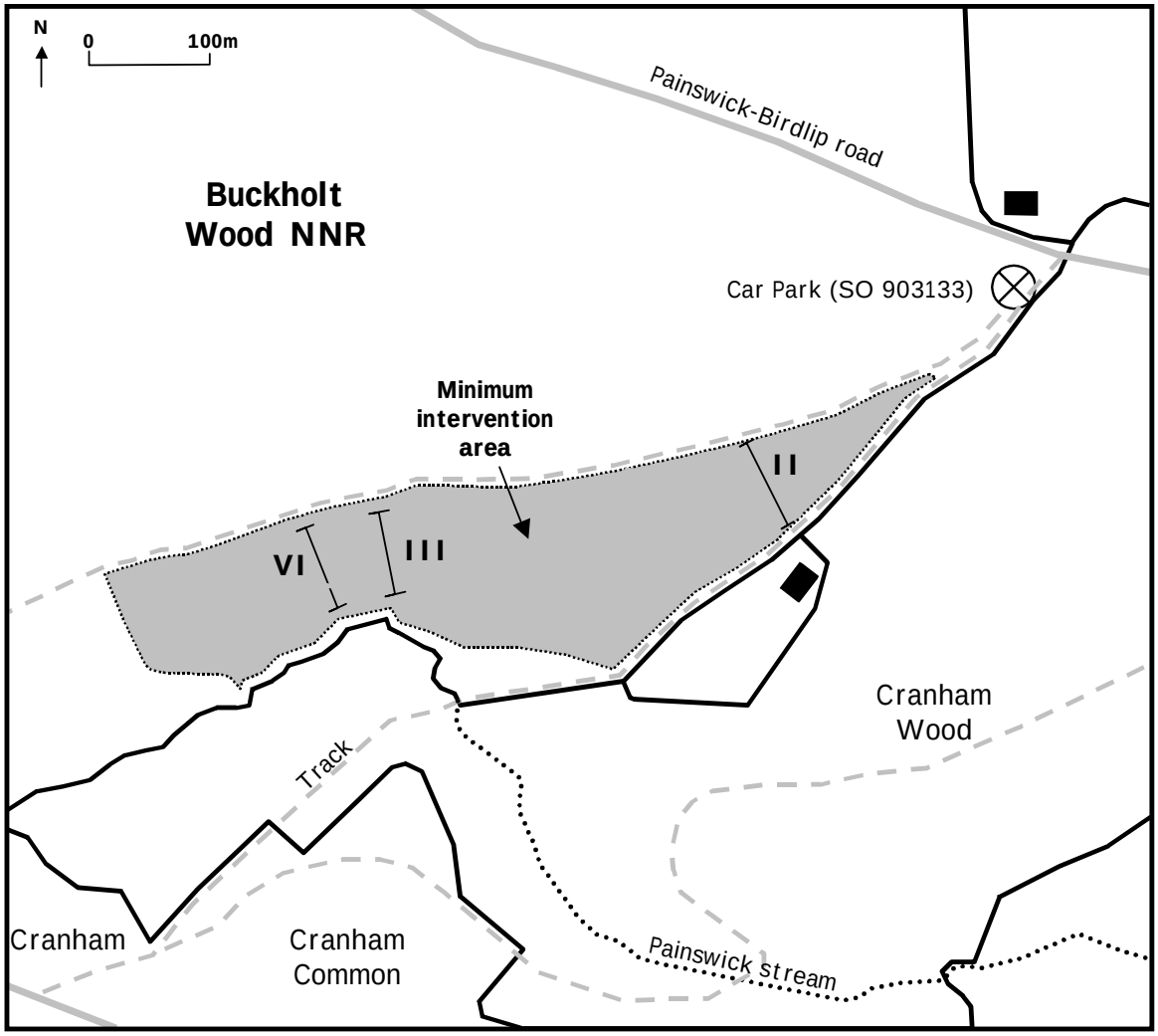
The study area was a typical example of the beech high forest, though dense patches of holly *Ilex aquifolium* and a few escapee *Cotoneaster* occurred. The ground vegetation was suppressed and often scarce because the tree canopy was closed and holly abundant. Ivy (*Hedera helix*) was the only frequent species. Occasional species were bluebell (*Hyacinthoides non-scriptus*), dog rose seedlings (*Rosa canina*), lords-and-ladies (*Arum maculatum*) and yellow archangel (*Galeobdolon luteum*). Rare species were ash as seedlings (*Fraxinus excelsior*), barren strawberry (*Potentilla sterilis*), bird's-nest orchid (*Neottia nidus-avis*), black bryony (*Tamus communis*), bramble (*Rubus fruticosus* agg.), broad-leaved helleborine (*Epipactus helleborine*), common/early dog-violet (*Viola riviniana/ reichenbachiana*), dog's mercury (*Mercurialis perennis*), hart's-tongue fern (*Phyllitis scolopendrium*), honeysuckle (*Lonicera periclymenum*), male fern (*Drypoteris filix-mas*), nettle-leaved bellflower (*Campanula trachelium*), traveller's-joy (*Clematis vitalba*), tufted hair-grass (*Deschampsia caespitosa*), wood anemone (*Anemone nemorosa*), wood barley (*Hordelymus europaeus*), wood brome (*Bromus ramosus*), wood melick (*Melica uniflora*), wood sorrel (*Oxalis acetosella*), wood spurge (*Euphorbia amygdaloides*), wood vetch (*Vicia sylvatica*), and woodruff (*Galium odoratum*).

3. Recording & analysis

Recording was carried out on three separate permanent transects (Figure 2). Each transect measured 20m x 60m (0.36ha), was marked centrally by galvanised posts, and numbered II, III or VI (they formed part of a suite of six transects some of which were in near-by stands

designated for active management). They were positioned in a 2ha compartment in the east end of the wood that was designated for management by minimum-intervention. The first 20m of transect II occupied a shallow sloping plateau, and the remainder was on moderate 10.5-16° slopes that lead down to a track in the bottom of a [part-dry tributary valley. Transects III and VI occurred on steep 17-27° slopes above the floodplain of Painswick stream, with only the last few metres showing any influence by the floodplain.

Figure 2 Location map showing features at the east end of Buckholt Wood, including the minimum intervention area, tracks and permanent transects therein



The transects were established in July 1992 (II), August 1992 (III), and October 1994 (VI), when the following details were recorded onto A3 charts (each covering a 20m-long transect section):

- Species and location (to nearest 10cm) of all live tree and shrub individuals that attained 1.3m height (including individuals close to the transect edge). Stems on multi-stemmed individuals were individually sketched. Small, densely-set holly stems occurred in some parts of the transect: although these could have been connected underground, each stem or group of stems that appeared to be growing as separate individuals was counted as such without disturbing the roots excessively.

- Girth (to nearest cm) at 1.3m breast height (gbh) of all live stems (including low forks) that attained 5cm gbh.
- Miscellaneous features, including large dead stumps and footpaths.

The transects were recorded again in June/July 2000, when the following details were overwritten onto the original charts or tabulated:

- Species, status and location as in 1992/4.
- Gbh (to nearest 0.5cm) of all stems (including low forks) that attained 5cm gbh.
- Miscellaneous features as in 1992/4.
- Notes on cause of death for each stem that had died since 1992/4.
- Each live stem was assigned to a crown layer and crown size category based on the position and spread, with adjustments made for the abundance of the foliage: *canopy* = crown mostly in uppermost layer and not overtopped, including those below canopy gaps (this was subdivided into an *upper canopy* formed by a scatter of trees to 20-30m height that had been retained during past fellings and which grew above a *lower canopy* formed by subsequent regeneration); *sub-canopy* = crown mostly just below and mostly overtopped by the canopy layer; *understorey* = crown mostly below sub-canopy layer; *ground* = crown mostly <2m height; *very large* = spread of more than about 10m diameter; *large* = spread about 6-10m diameter; *medium* = about 3-5m diameter; *small* = about 2m diameter; *very small* = <1m diameter.
- Each live stem was described briefly, with notes made on stature, forking, vigour, crown condition, epicormics, damage, debarking, climbers, and origin as coppice or pollard. The longest descriptions were made for upper canopy trees and the briefest for small stems.
- Each live stem was scored for grey squirrel bark-stripping damage using a five-point scale (Mountford 1997): 0 = *none* = no bark removed; 1 = *limited* = one or few small patches with <10% bark circumference removed; 2 = *moderate* = one large or few medium and/or many small patches with 10-50% circumference removed; 3 = *severe* = few large and/or many medium and many small patches with >50% circumference removed; 4 = *very severe* = as for severe but ring-barked. Damage included that to the trunk and main forks, with the upper branches being viewed from the ground with binoculars. Bark-stripping was recorded first for the lower trunk (<2m height) and then for the upper trunk (>2m height), with the maximum score used to categorise overall damage, i.e. scores of 1/3, 3/3 and 3/1 were all categorised as severe damage.
- Each dead standing stem (and those only alive <1.3m height) that attained 1.3m height and 10cm gbh had its height (estimated to the nearest m), decay state (categorised as solid or part-rotten), and remaining bark (to nearest 10%) estimated.

The data set provided a large volume of information on over 3100 stems. To facilitate sorting, statistical analyses, and long-term storage, the information was entered on to a Microsoft Excel spreadsheet. Most stems were confidently re-identified, but a few anomalies were detected and adjustments had to be made. A few individuals were incorrectly identified or misplaced, and a few appeared to have been omitted. It was difficult to decide where girth measurement had been taken on stems that had fallen over, were bent or had forks, kinks, bulges, bosses or damaged bark at 1.3m height. In dealing with size anomalies, amendments

were made where records were missing or the difference was considered implausible. This was achieved by interpolating from the known performance of similar stems located nearby. For analysis, live individuals/stems included those standing or fallen and with live leaves at or above 1.3m from the base. Losses included those that were reduced to alive below 1.3m height. Basal areas were calculated assuming stems were circular in cross section.

In 2000 the amount of fallen dead wood was estimated for the whole compartment using the line-transect method of Warren & Olson (1964). Ten equal length line transects covering 200m in total (t) were laid out using random start points and directions. The number (N) of fallen dead wood stems attaining 5cm diameter and intersecting the line was counted, their diameter (d) measured in cm at the intersection, and the species identified. The volume (V) ($m^3\,ha^{-1}$) of fallen dead wood was estimated using the formulae, $V = \sum(\pi^2 d^2/8t)$.

4. Results

4.1 General stand composition

The transects were initially dominated by beech, with holly, whitebeam, hawthorn, ash and yew accounting for most of the remaining individuals/stems (Tables 1-2). Amongst eleven other minor species, pedunculate oak, sycamore and field maple were most numerous.

The structure of the stands matched with the known history of management for the wood. Records of management (Nature Conservancy Council 1990) state that some major felling occurred in the wood in 1947 and from 1957 localised fellings occurred under a Forestry Commission Woodland Dedication Scheme. The latter specified that mature stands of up to 0.13ha could be felled to develop advance regeneration, with restocking to relying principally on natural regeneration but with beech to be planted where this was insufficient. Thinning was to be carried out in stocked areas of 40 years age upwards.

On the transects, scattered trees and groups of trees retained during past fellings were represented by 31 beech of 95.5cm gbh or more in 1992/4. These formed the upper canopy (Table 3), were typically about 25m tall and more-or-less straight-trunked with few low forks. Evidence of trees cut out in the past was recorded in 35 large stumps of beech with felling marks that were scattered throughout the transects. The date when these trees were felled is not known precisely, but most had apparently been felled synchronously several decades ago (perhaps in 1947 or soon after 1957). A single large beech located about two-thirds of the way down transect VI appeared to have been felled later, perhaps 20 years ago.

Post-felling regenerants were represented by numerous small and medium-sized trees, which appeared to have regenerated naturally without subsequent thinning. The largest of which had developed into a lower canopy and sub-canopy about 10-15m height. These were mainly beech, with some whitebeam and ash and a few pedunculate oak and goat willow (Table 3). The beech were widespread, whereas the ash occurred mainly on the plateau at the top of transect II (where holly was limited). The smaller trees and shrubs were mainly of beech, whitebeam, holly, hawthorn and yew, but they also included nearly all the stems of the minor species. The whitebeam, holly and yew occurred mainly on the steep-sloping parts of the transects, whilst the hawthorn occurred mainly where holly and yew were limited. The smaller trees and shrubs dominated the lower strata (Table 3) and included: (i) slow-grown regenerants of most species in the sub-strata that had become overtopped and suppressed by

faster-grown recruits; (ii) numerous healthy, bent over or lateral holly stems that formed a dense, low-growing layer mainly on steep-slopes; (iii) a similar layer of yew, though this was erect-growing and occurred mainly on upper steep-slopes; and (iv) a group of regeneration below the younger canopy gap on transect VI, which was mostly of suppressed ash, whitebeam, hawthorn and beech.

Most trees were single-stemmed maidens (derived from seed), whilst most shrubs were multi-stemmed. The largest beech at 325cm gbh was the only ex-pollard. A minority (95) of individuals (excluding most multi-stemmed shrubs) were adjudged to be coppice-origin. Over half of these (51) were beech, including a group at the base of transect VI that formed a distinct area dominated by beech-coppice. Most (13 out of 17) of the ash coppice occurred in the middle section of transect II. Otherwise, coppice individuals were scattered and included some whitebeam (18), yew (6), oak (2), and sycamore (1). A small number of individuals (33) were derived from stems that had been crushed during past felling operations but had regrown. These included some beech (16) and ash (7), and a few hawthorn (6), sycamore (2) and whitebeam (2).

4.2 Stand change from 1992/4 to 2000

Changes from 1992/4 to 2000 (Tables 1-5) reflected a period of largely undisturbed growth. About 15% of stems and 17% of individuals died due mainly to competitive exclusion, whilst the basal area of live stems increased by 11% as the most vigorous surviving trees grew strongly.

Beech remained dominant in both canopy layers, though most beech stems remained in the lower strata. Its basal area and the number of medium-large stems increased, because losses were concentrated in the smaller size-classes and most (69 out of 122) medium-large survivors in the canopy increased by at least 5cm gbh. Survivors in the lower strata were suppressed by the canopy shading: although many retained healthy foliage most increased little in girth, the average being <1cm gbh. Losses amounted to 85 individuals and 71 stems sized 5cm gbh or more. Most of these (81 individuals, 66 stems) were excluded, but squirrel debarking (2 individuals, 3 stems) and cutting associated with the ride at the top of transect II (2 individuals, 2 stems) were responsible for a few losses. Four stems (three lateral trunk shoots on existing stems and a small suppressed sapling) that grew to 5cm gbh or more recruited, but only one new individual formed, a weak, lateral-growing seedling. Beech suffered from bark-stripping damage by grey squirrels. In 2000, 20% of live stems attaining 5cm gbh had been at least partly damaged, the worst damage being associated with middle-sized stems of 20-80cm gbh (Table 6).

Other species remained scare in canopy, apart from on the plateau at the start of transect II where ash remained important. It increased substantially in basal area, mainly because here stems above 20cm gbh that remained in the canopy grew rapidly. Nevertheless, ash suffered substantial losses of smaller sized stems (64 out of 144 stems sized 5-20cm gbh and 77 out of 175 individuals) due to overtopping and exclusion. All surviving stems in the lower strata also remained much suppressed by shading and grew little. Ash made limited recruitment with 12 saplings growing above the 1.3m height threshold and 10 stems growing above the 5cm gbh threshold. All had grown slowly since 1922/4 and most were associated with the recent canopy gap on transect VI.

Otherwise, pedunculate oak and goat willow survived as rare components of the canopy. Oak was occasional on transect II where 18 of the 20 live individuals in 1992 occurred, but by 2000 exclusion had reduced it to just 5 surviving individuals, only two of which were in the lower canopy with very small, compressed crowns. Goat willow was reduced with the loss of all five smaller individuals to a single, surviving, healthy, 55cm gbh tree located in the lower canopy at the base of the main slope on transect VI. Both species failed to recruit.

A small number of whitebeam survived in the lower canopy, and a few made rapid-growth where they were part-released by small gaps in the canopy. However, most remained in the lower strata and especially the understorey, reflecting considerable tolerance to shading. Its basal increase was slight because losses were moderate and most survivors grew little (average <1cm gbh). Losses were of smaller, suppressed stems due to exclusion and no recruitment occurred.

Holly was strongly shade-tolerant. It remained dominant in the ground layer to 2m height, with most (483 out of 647) stems having grown laterally. Only 98 out of 647 stems, including most above 20cm gbh, had developed into the understorey. Its basal area and density changed little: although losses were limited (and mainly of small, excluded stems) and some recruits developed, growth of survivors was slow (average <0.5cm gbh). Recruiting stems and individuals were all slow-growing. Most (30 out of 55) new individuals developed in the last section of transect III or the first section of transect VI, i.e. where holly was already most abundant. 47 grew laterally and 25 came from stems that had layered a short distance from their base.

Hawthorn remained occasional in the understorey and ground layers. It decreased slightly in basal area and moderately in density because mortality was substantial, recruitment limited, and most survivors grew little (average <0.5cm gbh). Exclusion accounted for most stem losses, though six stems were cut beside the ride at the start of transect II and deer fraying killed one. 7 out of 8 individuals that recruited occurred in the last section of transect III: these were slow-growing, old seedlings, located where the ground levelled into the floodplain and side-light was moderate because two medium-sized beech trees had been felled before 1992 leaving small canopy gaps.

Yew was highly shade-tolerant and remained locally frequent in the lower strata. It increased slightly in basal area and was the only species to increase in density. Survival rates were high and most of the largest surviving stems increased by 3-9cm gbh. 4 out of 5 new individuals were from a cluster of layers that had grown from a low, horizontal-grown stem.

Some minor understorey species changed little. All sycamore stems above 5cm gbh survived and only one small individual died due to exclusion. However, grey squirrels had severely debarked 2 out of 3 largest sycamore stems and killed the original tops in these. Wych elm increased slightly in density as all larger stems survived, and two individuals recruited at the very bottom of transects II and III to make up for a small individual that was excluded. All rowan individuals survived and it increased slightly in stem density as several stems made it to 5cm. The single, small guelder rose remained alive but with little live foliage. Crab apple was reduced from three to two small individuals.

Other minor understorey species declined substantially. Field maple decreased as 7 several small individuals out of 13 died due to exclusion, though all stems above 5cm gbh survived. Hazel declined strongly as 4 out of 7 individuals died and the only surviving stems were

<5cm gbh. Dogwood individuals declined from five a single, much suppressed, 5cm gbh survivor. The two small cotoneaster bushes were excluded.

4.3 Dead wood in 2000

In 2000, standing dead wood volume was estimated at 3.3m^3 $ha^{-1}$and fallen dead wood at 3.0m^3 ha^{-1} (Table 7). Most of this was beech, with various other species making minor contributions. The largest snags were three subsidiary stems on a large beech stool sized 32-62cm gbh, but snags were mostly sized <20cm gbh and accounted for <0.02m^3 ha^{-1} each. The fallen dead stems ranged from 5-11cm diameter and mostly accounted for <0.025m^3 ha^{-1} each.

5. Discussion

The study area provides an example of a calcareous beechwood growing on clayey rendzina soils over limestone. This has been retained more-or-less untreated for several decades during which natural processes have dictated most of the stand change. Using the stand characteristics recorded in 1992/4 and the changes to 2000, some features and broad patterns of stand change are discernable.

5.1.1 Stand composition was partly influenced by site condition

All areas conformed to the W12 *Fagus-Mercurialis* woodland community of the National Vegetation Classification (Rodwell 1991), but there was a distinct difference between the upper plateau and the sloping ground below. On the former, where the soils were deeper, more clayey and less free-draining, ash was most prominent and proved most competitive, hawthorn remained occasional, and a few oak survived in the lower canopy. Where the ground sloped steeply and the soil was a shallow clayey rendzina, most whitebeam individuals occurred and there was a dense understorey of holly or sometimes yew. This reflected a change from the W12a *Mercurialis perennis* sub-community, through the W12b *Sanicula europaea* and W12c *Taxus baccata* sub-communities of the *Fagus-Mercurialis* woodland type, which is typical of such a transition in topography (Rodwell 1991).

5.1.2 Stand structure remained strongly influenced by past management

Although the stand has recently been treated by minimum intervention, the structure remained strongly influenced by past management. This was reflected by the five main different aged elements: (i) a single large, old pollard beech; (ii) a scatter of mature, upper canopy beech trees; (iii) a large cohort of regeneration of c.40-50 years age; (iv) a small cohort of tree regeneration in one location of c.20 years age; and (v) an on-going cohort of recent understorey regeneration of mainly holly. The first and oldest feature was residual from when the wood was moreover treated as a wood-pasture and common rights for livestock grazing were exercised (Nature Conservancy Council 1990). The upper canopy beech represented trees that had been retained during group felling operations undertaken sometime around 1947-57 or soon after. These remained dominant in 2000 and formed a canopy layer above a mass of post-felling regeneration, some of which was clearly derived from coppice or crushed stems. In the one place where a pocket of younger tree regeneration occurred, a large beech had been felled perhaps only 20 years ago. In addition to these past-management effects, the edge of the stand was clearly influenced by felling in adjacent compartments, which allowed more side-lighting and had facilitated some regeneration on

the lower slopes and perhaps the development of shade-tolerant shrubs in the understorey. Also, since 1994 there had been a little direct tree cutting along the stand edges associated with the management of an adjacent ride.

5.1.3 The stand contained some features associated with mature natural woodland

Despite the imprint of past-management, the stand had inherited or developed several features associated with semi-natural, mature, relatively undisturbed woodland (Peterken 1996). Most of the trees and shrubs were native species that had developed from natural regeneration. The only non-native to persist was sycamore, which comprised a few stems mainly in the understorey, the largest of which was badly damaged by squirrel debarking. The negative exponential stem size-distribution and mixture of tree ages reflected the various episodes of regeneration and survival of mature and veteran beech trees within the stand, whilst the well-developed, multi-layered stratification reflected a period of prolonged natural development. Indeed, over the last 40-50 years disturbance appeared to have been limited to some recent small-scale cutting associated with an adjacent ride and the single felling of canopy beech about 20 years ago. Despite these features, the stand remained below thresholds associated with old-growth woodland: the basal area was moderate, large trees were rare, and little standing or fallen dead wood was present. These will take several decades to develop, depending greatly on the intensity, scale and frequency of future disturbances and responses to these.

5.1.4 The trend was towards increasing dominance by beech, holly, whitebeam and yew

The abundance and performance of the species differed. Beech remained dominant in both canopy layers and abundant in the lower strata. It appeared highly shade-tolerant and looked set to remain as the major tree within most of the stand. Although it had suffered from debarking by grey squirrels, damage to even the most vulnerable size-class was limited, evidently because the stand remained closed and growth of pole-sized trees slow (Mountford 1997; Mountford & Peterken 1999; Mountford *et al* 1999). Amongst the other species, ash appeared capable of sustaining itself in the canopy only on the upper plateau, though a few moderately vigorous recruits were developing in the c.20 year old gap. Despite oak having regenerated and remained moderately abundant for a few decades, only on the upper plateau did it look likely that any oak poles might survive the next few decades. The only other species likely of sustaining a presence in the canopy was goat willow, but only as a minor component on the lower slopes adjacent to the floodplain.

Holly appeared strongly shade-tolerant and looked set to increasingly dominate the ground layer. Whitebeam looked capable of making some advances into the lower canopy and sub-canopy through the release of suppressed poles, but mainly it appeared capable of sustaining itself in the lower strata in moderate shade. Yew replaced holly in places as the dominant shrub, appeared equally as shade-tolerant and even more capable of growing into large-crowned individuals. Hawthorn looked set to remain occasional, as it was only moderately tolerant of shading but capable of regenerating in small gaps and below the canopy with adequate side-light. Amongst the minor species, field maple, goat willow, sycamore, rowan and wych elm looked set to remain at low levels, whilst crab apple, dogwood, guelder rose and hazel could be lost within the next few decades.

5.1.5 Stand development was mainly towards an increasing dominance by shade-tolerant species due to undisturbed growth, stem exclusion and understorey reinitiation

The main general trends recorded by the transects, which have probably applied since the stand regenerated, were: (i) limited canopy disturbance; (ii) decreasing stem density; (iii) disproportional loss of small-sized stems and shade-intolerant species due to exclusion (ash, hazel, oak, dogwood, goat willow); (iv) increasing basal area; (v) disproportional growth of medium-large stems; (vi) disproportional survival of shade-tolerant species (beech, holly, whitebeam, hawthorn, and yew); and (vii) development of shade-tolerant shrubs in the understorey (holly and yew). Thus the major processes can be summarized as undisturbed growth, stem exclusion, increasing dominance by shade-tolerant species, and understorey reinitiation. These changes are characteristic of relatively undisturbed, maturing, temperate forest stands passing through the stem exclusion and understorey reinitiation stages of stand development (Oliver 1981; Oliver & Larsen 1996).

As the stand progresses towards old-growth status, it seems it will become increasingly dominated by beech in the canopy and holly and yew in the understorey. Beech is widely recognised throughout north-west Europe as a strongly competitive, shade-tolerant tree that normally ends up dominating mature, untreated stands, sometimes with ash or oak co-dominant (eg Pontailler *et al* 1997; Emborg *et al* 2000). Holly sometimes develops naturally as an underwood below old beech stands depending on site conditions and the degree of browsing by deer/livestock (Peterken & Jones 1987; Mountford *et al* 1999, 2001; Mountford 2001; Mountford & Peterken 2001). AS the stands get older they will become increasingly vulnerable to senescence and damage by windstorms and drought. Once the stand starts to open the volume of dead wood will increase and opportunities for gap-phase regeneration will develop. Small gaps are likely to be filled with beech or ash or possibly existing bushes of holly or yew: unless major disturbances occur, there will be limited opportunities for light-demanding species to sustain themselves, except along the stand edges. The development of any regeneration will depend on the abundance of deer. Although grey squirrels have so far caused limited damage, their debarking is likely to increase wherever beech (or sycamore) poles within the vulnerable size range of 20-80cm gbh are released into vigorous growth (Mountford 1997; Mountford & Peterken 1999, Mountford *et al* 1999).

6. Recommendations for research and monitoring

The recording of the permanent transects in Buckholt Wood combines with similar studies at other minimum intervention reserves that are starting to yield valuable information on natural stand development in British woodland (Mountford 2000). Recommended recording of these is every decade or so, but any intervening impacts or events should be noted preferably by means of an annual inspection, when the state of the transect markers can also be checked. Both of these activities should be written into the management plan and the recorded information archived.

It would be useful to add to the existing monitoring by: (i) recording the ground vegetation along the transects, say, by estimating ground cover within each 10x10m subplot and/or within a set of 1x1m subplots taken along the transect mid-line; (ii) establishing a set of representative plots on a grid or other system where trees, shrubs, dead wood and ground vegetation can be recorded; and (iii) studying other features of interest (see Mountford 2000 for details).

The minimum intervention is rather small, narrow and vulnerable to edge effects, and represents only part of the variation in the beech woodland within the reserve. Further, larger blocks of minimum intervention would be useful for research and monitoring and help increase the amount of old-growth habitat within the reserve.

There are three other transects in an adjacent compartment that is due for management by selective felling. These ‘managed’ transects provide a basis to compare stand development under contrasting regimes and are due for a second recording.

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Appendix: Tables

Table 1 Change in the density (n ha^{-1}) and basal area (m^2 ha^{-1}) of live individuals/stems within all transects from 1992/4 to 2000. Based on individuals attaining 1.3m height (or length if fallen or bent over), stems attaining 5cm gbh, and standing/bent over/fallen individuals/stems that were alive at 1.3m from the base.

	Density of individuals		**Density of stems**		**Basal area of stems**	
	1992/4	**2000**	**1992/4**	**2000**	**1992/4**	**2000**
Major species						
Beech	1131	897	1183	997	23.40	25.89
Holly	1928	1881	1925	1797	1.47	1.48
Whitebeam	542	394	725	550	1.25	1.29
Hawthorn	542	406	436	336	0.42	0.39
Ash	486	306	400	250	0.89	1.19
Yew	144	153	364	375	0.64	0.89
Minor species						
Pedunculate oak	56	14	44	14	0.12	0.11
Sycamore	47	44	31	31	0.07	0.08
Field maple	36	19	28	36	0.02	0.03
Hazel	19	8	19	-	0.02	-
Goat willow	17	3	8	3	0.06	0.07
Wych elm	14	17	8	8	0.01	0.01
Rowan	11	11	17	25	0.01	0.01
Dogwood	14	3	3	3	<0.01	<0.01
Crab apple	8	6	8	6	<0.01	<0.01
Cotoneaster	6	-	6	-	<0.01	-
Guelder rose	3	3	-	-	-	-
All species	5003	4164	5206	4431	28.40	31.43

Table 2 Size-distribution of live stems within all transects (0.36ha) in 1992/4 and change by 2000. Based on standing/bent over/fallen stems alive at 1.3m from the base and attaining 5cm gbh.

	Gbh class (cm)						
	<20	**20-<40**	**40-<60**	**60-<80**	**80-<100**	**100-315**	**Total**
1992/4							
Beech	239	103	40	10	4	30	426
Holly	672	21	-	-	-	-	693
Whitebeam	222	35	4	-	-	-	261
Hawthorn	148	8	1	-	-	-	157
Ash	108	34	2	-	-	-	144
Yew	106	24	1	-	-	-	131
Others	52	9	1	-	-	-	62
Total	1547	234	49	10	4	30	1874
Change by 2000							
Beech	-74	-3	+5	+3	+1	+1	-67
Holly	-49	+3	0	0	0	0	-46
Whitebeam	-65	-1	+3	0	0	0	-63
Hawthorn	-37	+1	0	0	0	0	-36
Ash	-56	-6	+8	0	0	0	-54
Yew	-3	+3	+4	0	0	0	4
Others	-16	-3	+2	0	0	0	-17
Total	-300	-6	+22	+3	+1	+1	-279

Table 3 Stratifictaion of all live stems within all transects (0.36ha) in summer 2000. Based on standing/bent over/fallen stems alive at 1.3m from the base and attaining 5cm gbh.

	Crown position					
	Upper canopy	**Lower canopy**	**Sub-canopy**	**Under-storey**	**Ground**	**Total**
Canopy species						
Beech	31	90	44	149	44	359
Ash	-	33	19	28	10	90
Pedunculate oak	-	2	1	2	-	5
Goat willow	-	1	-	-	-	1
Understorey species						
Holly	-	-	-	98	549	647
Whitebeam	-	12	40	121	25	198
Hawthorn	-	-	-	61	60	121
Yew	-	-	-	57	78	135
Field maple	-	-	1	6	6	13
Sycamore	-	-	1	10	-	11
Rowan	-	-	-	7	2	9
Wych elm	-	-	-	2	1	3
Crab apple	-	-	-	-	2	2
Dogwood	-	-	-	1	-	1
Total	31	139	106	542	771	1595

Table 4 Fate and recruitment of live stems within all transects (0.36ha) from 1992/4 to 2000. Based on standing/bent over/fallen stems alive at 1.3m from the base and attaining 5cm gbh. Species are ranked according to the percentage change (last column).

	1992/4	**Fate by 2000**			**2000**	**1992/4-2000**			
	Stems alive	**Survived**	**Died**	**Recruited**	**Stems alive**	**Survival rate**	**Mortality rate**	**Recruit-ment rate**	**Change**
	(n)	**(n)**	**(n)**	**(n)**	**(n)**	**(%)**	**(%)**	**(%)**	**(%)**
Major species									
Yew	131	130	1	5	135	99	1	4	3
Holly	693	618	75	29	647	89	11	4	-7
Beech	426	355	71	4	359	83	17	1	-16
Hawthorn	157	115	42	6	121	73	27	4	-23
Whitebeam	261	198	63	-	198	76	24	0	-24
Ash	144	80	64	10	90	56	44	7	-38
Minor species									
Rowan	6	6	-	3	9	100	0	50	50
Field maple	10	10	-	3	13	100	0	30	30
Sycamore	11	11	-	-	11	100	0	0	0
Wych elm	3	3	-	-	3	100	0	0	0
Dogwood	1	1	-	-	1	100	0	0	0
Crab apple	3	2	1	-	2	67	33	0	-33
Goat willow	3	1	2	-	1	33	67	0	-67
Pedunculate oak	16	5	11	-	5	31	69	0	-69
Hazel	7	-	7	-	-	-	100	0	-100
Cotoneaster	2	-	2	-	-	-	100	0	-100
All species	1874	1535	342	60	1595	82	18	3	-15

Table 5 Fate and recruitment of live individuals within all transects (0.36ha) from 1992/4 to 2000. Based on standing/bent over/fallen individuals alive at 1.3m from the base. Species are ranked according to the percentage change (last column).

	1992/4	Fate by 2000			2000	1992/4-2000			
	Individuals alive	Survived	Died	Recruited	Individuals alive	Survival rate	Mortality rate	Recruitment rate	Change
	(n)	(n)	(n)	(n)	(n)	(%)	(%)	(%)	(%)
Major species									
Yew	52	50	2	5	55	96	4	10	+6
Holly	694	622	72	55	677	90	10	8	-2
Beech	407	322	85	1	323	79	21	0	-21
Hawthorn	195	138	57	8	146	71	29	4	-25
Whitebeam	195	142	53	-	142	73	27	0	-27
Ash	175	98	77	12	110	56	44	7	-37
Minor species									
Wych elm	5	4	1	2	6	80	20	40	20
Guelder rose	1	1	-	-	1	100	0	0	0
Rowan	4	4	-	-	4	100	0	0	0
Sycamore	17	16	1	-	16	94	6	0	-6
Crab apple	3	2	1	-	2	67	33	0	-33
Field maple	13	6	7	1	7	46	54	8	-46
Hazel	7	3	4	-	3	43	57	0	-57
Pedunculate oak	20	5	15	-	5	25	75	0	-75
Dogwood	5	1	4	-	1	20	80	0	-80
Goat willow	6	1	5	-	1	17	83	0	-83
Cotoneaster	2	-	2	-	-	0	100	0	-100
All species	1801	1415	386	84	1499	79	21	5	-17

Table 6 Grey squirrel bark-stripping damage scores to live beech stems within all transects (0.36ha) in summer 2000. Based on standing/bent over/fallen stems alive at 1.3m from the base, attaining 5cm gbh and scored for damage both below and above 2m. The number of stems in various damage-categories and size-classes are shown. The worst damage was to stems sized 20-79.9cm gbh: 52 out of 173 of these had been at least moderately damaged, compared to 3 out of 203 in other size-classes ($\chi^2 = 61.1$, $p<<0.001$).

G.b.h. class	Bark-stripping category					
(cm)	None	Limited	Moderate	Severe	Very severe	Total
<20	174	0	0	1	0	175
20-39.9	78	11	7	10	4	110
40-59.9	18	7	16	8	0	49
60-79.9	5	2	4	3	0	14
80-99.9	3	0	2	0	0	5
100-320	23	0	0	0	0	23
Total	301	21	31	25	8	386

Table 7 Amount of dead wood in the study area in 2000. Standing dead wood is based on snags attaining 1.3m height and attaining 10cm gbh within all transects and is presented as density (n ha^{-1}), basal area (m^2 ha^{-1}), and volume (m^3 ha^{-1}). Fallen dead wood is based on toppled stems attaining 5cm diameter within the compartment as measured on line transects and is presented as length (m ha^{-1}) and volume (m^3 ha^{-1}).

Snags	**Density**	**Basal area**	**Volume**
Beech	47	0.24	2.24
Whitebeam	50	0.06	0.37
Pedunculate oak	14	0.03	0.23
Hawthorn	17	0.02	0.05
Holly	44	0.06	0.17
Ash	22	0.02	0.14
Hazel	6	0.01	0.05
Goat willow	3	0.01	0.05
Yew	3	<0.01	0.01
All species	206	0.46	3.31
Fallen dead wood	**Length**		**Volume**
Beech	864		2.12
Whitebeam	79		0.75
Holly	79		0.15
All species	1021		3.02

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