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Natural developments at Scords Wood, Toy's Hill, Kent, since the Great Storm of October 1987

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Preface

English Nature is grateful to ECOSCOPE, in particular to Ed Mountford and George Peterken, for the opportunity to include this report in its research report series. This should help to ensure that knowledge of the transects 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

Summary

Changes brought about by the Great Storm of October 1987 in an a minimum intervention beech-oak-holly wood-pasture at Toy's Hill, Kent, were quantified by means of a permanent transect, recorded one, four and eleven years after the event. Before the storm, the stand was dominated by old, outgrown beech pollards mixed with oaks, which had probably remained undisturbed by managers for about a century.

The storm devastated the stand. Canopy cover was reduced to 2%. Most trees were blown towards WSW-NNW leaving root plates 2-3m high and 3-5m wide. Most shrubs, saplings and sub-canopy trees were snapped or crushed. In 1988 most standing and fallen trees were still alive, though some fallen trees were dead or obviously dying. The crowns of fallen live trees covered nearly one-quarter of the ground, branch debris was abundant, but several patches remained uncovered and fully-lit.

Four growing seasons later, several fallen trees had died, regeneration had begun in earnest, and the ground vegetation had developed strongly. Open patches were filling with birch seedlings, and holly had resprouted vigorously. Willowherb *Chamerion angustifolium* and foxglove *Digitalis purpurea* had become abundant, and hard fern *Blechnum spicant* was common pits left by root plates.

Eleven growing seasons after the storm, most fallen and large standing trees had died. Survivors were growing weakly and more by fresh sprouts than crown expansion. About half of the smaller beech had survived and most were spouting. All hollies present before the storm survived and were sprouting vigorously. Regeneration was patchy. In the open patches that had remained free of debris, birch regeneration was copious, but few birches had become established in patches covered by debris, live crowns or holly thickets. The most vigorous birches, which were either isolated or marginal to the main clumps, had grown at about 1cm d.b.h. per year and 1m height per year. Other recruits were scarce, and amounted to three beech, including one individual that grew from a root nodule, one vigorous rowan, two weak oaks, and one spindly willow. Volumes of fallen dead wood remained exceptionally high at >400m^3 ha^{-1}. Most bollings and trunks were little decayed, but branches and smaller trunks had lost most twigs and were visibly decaying. Some root plates had part- or mostly slumped back into their hollows. Bramble *Rubus fruticosus* agg. and bracken *Pteridium aquilinium* dominated the ground vegetation, but both were limited to well-lit gaps. Bramble had scrambled over piles of branch debris, but bracken covered only areas with few logs. Hard fern round hollows had been much reduced.

These changes appeared reasonably representative of the minimum-intervention reserve as a whole. Whilst there had been limited recovery of some standing and fallen beech and oak, the

former old-growth beech-oak stand had been converted by the storm into birch-dominated young-growth.

Contents

Site details and methods

Situation and status

Scords Wood (national grid reference TQ 475 522) is part of a 154ha area of ancient woodland and heath which is owned and managed by the National Trust. It is situated near the small village of Toy's Hill, 7km southwest of Brasted, Kent. It was formerly managed as wood-pasture and coppice and contained many large outgrown beech pollards. Scords Wood is part of a Site of Special Scientific Interest (SSSI) and is a Nature Conservation Review site (Ratcliffe 1979).

Topography, soils, & vegetation

The site occupies an east-facing slope that rises from 170-240 m. It is part of the Lower Greensand escarpment that cross north Kent and is mostly underlain by free-draining acid soils.

On the higher, gradually sloping ground that was formerly treated as wood-pasture, the woodland was dominated by beech *Fagus sylvatica* pollards, pedunculate oak *Quercus robur*, and birch *Betula pendula*, together with a few holly *Ilex aquifolium*, rowan *Sorbus aucuparia*, and willow *Salix caprea/cinerea*. Most of the beech and oak were toppled in the storm of 1987, and the others are mainly post-storm recruits. The ground vegetation is dominated by either bramble *Rubus fruticosus* agg. or bracken *Pteridium aquilinum*, although large areas remain covered solely by trunks and branches from the fallen beech and oak. This woodland conforms to type W14 *Fagus sylvatica-Rubus fruticosus* of the National Vegetation Classification (Rodwell 1991).

History

Scords Wood has a long history of human usage (Moseley & Moor 1988; Widdicombe 1996). In 1295, Robert Toys, presumably the eponym, was given the Rights of Pannage to the area. As part of the Common of Brasted, common rights for pigs and cattle grazing, firewood collection, peat cutting and chert mining existed until 1853 when the site was enclosed. Grazing appears to have then been abandoned and beech regenerated or was planted in. Traditional pollarding of beech and coppicing of oak for firewood and for charcoal manufacture continued until the 1930s, but thereafter the stands were largely left to develop naturally.

In the Great Storm of October 1987, much of the plateau beech wood-pasture was levelled, whilst the marginal oak coppice was part-damaged. Although much of the levelled woodland was consequently cleared and replanted or left to natural regeneration, a central 20ha block in Scords Wood was dedicated to non-intervention and here no clearance or replanting occurred (Hutton 1989; King 1994).

Long-term monitoring programme

Scords Wood was selected for inclusion in a programme of research into the immediate and long-term effects of the storm of October 1987. This work was commissioned by the Chief Scientist's Directorate of the Nature Conservancy Council, under the general supervision of Dr. George Peterken. It was part of a widespread interest into the ecological responses to the 1987 Great Storm (Whitbread 1991; Kirby & Buckley 1994; Peterken 1996), and established a baseline to

follow the natural long-term development of the wood. In 1992, English Nature funded a follow-up survey.

Most recently, Scords Wood and several other sites have been resurveyed as part of a national programme of long-term monitoring in unmanaged woodland nature reserves. This was established by Nature Conservancy Council during the 1980s and includes a range of mature, unmanaged, mixed woodlands across the country (Peterken & Backmeroff 1988; Hall, Kirby & Morecroft 1999). The aim is to monitor the performance of trees, shrubs and saplings in these woods at roughly decade intervals, thereby enhancing our knowledge of natural woodland development and the processes that drive changes in these woods.

The re-recording of these sites formed part of the RENFORS project - REgeneration of Native FORest Stands for timber production and environmental value - funded by the Commission of the European Communities Directorate-General for Agriculture.

Permanent transect records

1988 records

The baseline records for Scords Wood were made by Dave Hutton, with the aim of providing a baseline for future monitoring and research into the regeneration of selected storm damaged woodland areas at the stand scale (Hutton 1989). During September/October 1988, he established and permanently marked a 20m-wide transect running across the centre of Scords Wood, and mapped two sections along this. This report deals with the mapped sections located at 180-277m along the transect. These covered 0.194ha and were dominated by beech pollards. The following details were recorded and archived as scale maps and tables in a report filed by the Nature Conservancy Council:

- Location, species, and status (alive or dead) of all individuals that had attained 1.3m height/length. Fallen windthrown trees were included. Some selected trees just outside the transect were also recorded.

- Girth at breast height (g.b.h. to nearest cm) of all stems measured with a tape. Some fallen trees could only be measured as an estimated diameter (d.b.h.), and all measurements were archived as diameters, with the girths converted by assuming stems were circular in cross-section. On coppice stools, small stems <5cm g.b.h. were recorded as <1cm d.b.h.

- Selected individuals under 1.3m height (prominent seedlings and stump regrowth) were recorded.

- All individuals were allocated to a growth form class (tree, coppice, pollard, shrub or juvenile based on Table 13.5, p.224, in Peterken 1981) and a height category based on five layers (emergent canopy, canopy, sub-canopy, shrub layer or sapling). Additional notes were made on the form of each individual.

- Fallen, leaning and broken trees were mapped onto the charts showing the location, diameter and length of the trunk and branches, and any associated root plate or old stump.

- The vertical projection of the surviving canopy was also mapped, showing canopy on standing trees and fallen trees separately.

1992 records

During 1992 Stephen Parker undertook a follow-up survey (Parker 1993, 1994), noting trees deaths, epicormic growth on surviving trees, root plate disturbance, new tree regeneration, and ground vegetation development.

1999 records

During 23-31 March 1999 a second follow-up survey was undertaken. This provided a small but detailed example of the consequent response to the 1987 October storm. The following detailed features were recorded from 200-244m on the right-side of the transect and from 210-244m on the left-side:

- Location, species, and status (standing alive above 1.3m height, fallen alive above 1.3m height, standing alive below 1.3m height, or dead standing) of all individuals that attained 1.3m height/length. Recruits were accurately mapped and complex multi-stemmed stools were individually sketched. Some selected trees just outside the transect were also recorded.

- Girth at breast height (g.b.h. to nearest 5mm) of all live and dead standing stems measured with a tape. Side forks and trunk shoots were measured if they arose below 1.3m height.

- Detailed notes were made on the condition of all surviving beech and oak trees, the decay condition of snags was assessed, and the most vigorous recruits were noted.

- Selected individuals under 1.3m height (prominent seedlings and stump regrowth) were recorded.

- Dead fallen windthrown trees were not directly measured but, along with the vertical position of canopy cover as viewed from the ground and areas covered by dense bramble, bracken, and brash, were sketched onto scale charts.

In the remainder of the section from 180-277m along, the same detailed records were made for surviving trees and recruits of all species except birch and holly, canopy cover and areas covered by dense bramble, bracken, logs or brash.

Analysis procedure

The data set provided a large volume of information concerning the fate of about 1100 stems. To facilitate sorting, statistical analyses, and long-term storage, the information was entered on to a Microsoft Excel spreadsheet.

Although most individual stems were confidently re-identified, a few difficulties were encountered and a few errors, omissions, and misidentifications appeared to have been made. It was difficult to decide where girth measurement had been taken on stems that had fallen over or had forks, kinks, bulges, bosses, or damaged bark at 1.3m height. Relocation of individual stems on multi-

stemmed individuals had to be done on the basis of minimum change, i.e. the largest stem in 1999 was assumed to have been the largest stem in 1988. In dealing with apparent errors, amendments were made where the difference was considered implausible, and by interpolating from the known performance of similar stems located nearby.

All trunk sizes were converted to diameters by assuming stems were circular in cross section. Live individuals were either standing or fallen and had live leaves above 1.3m from the base.

Statistical procedure followed Zar (1984) and tests were carried out using *Microsoft Excel Version 7.0a* and *Statistica Release 4.5* computer packages. Stem growth was assessed by examining changes in the d.b.h. of stems that remained alive at the end of the 10 growing seasons.

Results

Stand condition before the 1987 storm

Table 1: Composition of the beech wood pasture transect immediately before the 1987 storm as reconstructed from records made in September/October 1988. Stem density and basal area include only live stems >1cm d.b.h.

	Beech	Oak	Holly	Rowan	All
Total number individuals	36	3	13	1	53
Pollards	19	-	-	-	19
Coppice	13	-	-	-	13
Self-sown trees	2	1	-	-	3
Standards	1	2	-	-	3
Tree from coppice	1	-	-	-	1
Small shrubs	-	-	13	1	14
Density individuals (n ha^{-1})	186	16	67	5	273
Stem density (n ha^{-1})	309	16	103	10	438
Basal area (m2 ha^{-1})	70.9	4.3	0.2	<0.1	75.4

The condition of the beech wood pasture stand was reconstructed using the records made in 1988 (Table 1), although these records potentially omitted some small understorey individuals that were crushed under toppled trees.

The old-growth character of the stand was revealed by the very high basal area (a consequence of abundant pollards in the stand) and low density of individuals and stems. The canopy appears to have been closed and dominated by outgrown beech pollards. Most of these were single-boled individuals ranging from 59-120cm d.b.h., but the two smallest trunks at 33 and 42cm d.b.h. were additional boles on a pollard first cut as coppice. Typically, bollings were 2-3m height, with 3-6 major secondaries, and the two largest secondaries ranging from 25-52cm diameter. Most of the pollards rose 15-25m into the canopy layer, and they were joined there by five other trees: three ex-standards, a beech at 90cm d.b.h., and two oaks at 50 and 81cm d.b.h.; a twin-stemmed beech promoted from coppice with the dominant stem at 63cm d.b.h.; and a slender self-sown oak at 38cm d.b.h.

Beech also numerous in the sub-canopy and shrub layer. 13 coppice individuals and two self-sown beech were probably present in the lower strata. Most coppice individuals appeared to have 2-3 main stems sized up to 17cm d.b.h. Both self-sown trees were 12cm d.b.h. In addition, 13 scattered shrub holly were present, most of which formed small bushes with the main stem 1-5cm d.b.h, but two were larger with the main stem at 9-10cm d.b.h. A single small shrub rowan was probably present: despite being omitted in 1988, it had developed into as a strong multi-stemmed stool by 1998.

There were a few notable large snags and stumps present: an 80cm d.b.h. beech pollard snag, a low-cut 1.1m tall beech pollard stump, a 1.8m tall shell of a large old holly pollard, and two 70cm diameter stumps from a felled oak and a decaying beech or holly stool. Other snags could have been present, but were overlooked because they were crushed and covered following the 1987 storm.

Thus, prior to the 1987 storm the woodland was a tall old-growth stand dominated in the canopy by beech with some oak. It was probably clear-cut about a century ago, when the beech understorey and pollards were cropped and a scatter of beech and oak standards retained. Although some intermediate felling appears to have occurred, probably for safety reasons, development appears to have been relatively natural.

Stand condition after the 1987 storm

The 1987 storm devastated the stand (Table 2). From near-closed, the canopy cover fell to 2%. Only three well spaced beeches that remained upright retained upper crown: two smaller pollards at 59cm and 78cm d.b.h. with 2-3 secondaries on top and one slender tree. Another beech pollard bolling survived with minimal damage: the small 33cm d.b.h. bolling on the three-boled pollard individual. The other six large individuals that remained standing suffered major crown loss: four beech pollards had most secondaries windsnapped within a few metres of the bolling top; the largest oak standard had most upper forks windsnapped high up; and on the three-boled pollard the middle-sized 42cm bolling fell having been windsplit from the ground and the largest 100cm bolling had forks windsnapped from two remaining large secondaries.

The remaining large trees were toppled by the storm: 11 beech pollards, two beech trees and the two smaller oak trees were windthrown, and a 90cm d.b.h. beech pollard was windsnapped close to the ground on one side of the bolling leaving a 1.5m tall shattered snag. The windthrow produced 14 hinged and one sheared root plate. Root plates were mostly 2-3m height, 3-5m across, and 0.5m deep, and the uprooting disturbed 5% of the ground within the transect. Direction of fall was recorded for 17 large windthrown trees, including two adjacent beech pollards that fell across the transect. They fell at 235-329° and most (16 out of 17) were within a 90° arc from WSW to NNW, the median direction being 293°: this indicated that intense gusts blew from ESE during the storm.

Table 2: Fate of individuals recorded in the beech wood pasture stand before the 1987 storm one year later. Unless stated, individuals remained alive.

	Beech			Oak	Holly	Rowan
	Pollards	**Standards & other canopy trees**	**Coppice & small self-sown trees**	**Standards & other canopy trees**	**Shrubs**	**Shrubs**
Standing with minor crown loss	2	-	1	-	5	-
Standing with major crown los	5	-	-	1	-	-
Windthrown	11	2	1	2	-	-
Windsplit dead	1	-	-	-	-	-
Hit by other trees & stems snapped off	-	-	5	-	2	-
Crushed, bent over or pinned by other trees	-	-	5	-	6	1
Hit by other trees, snapped off & dead	-	-	2	-	-	-
Hit by other trees & leaning over	-	-	1	-	-	-

Although a five-stemmed coppice beech was directly windthrown, most lower strata individuals suffered damage because they were indirectly struck by the toppled pollards and canopy trees. On coppice and small-self sown beech individuals, seven had the tops snapped off all or most main stems, five others were completely crushed, and one survived leaning over by 40° beneath some windsnapped oaks limbs. Four hollies were bent over and two holly were pinned by toppled trees. Two other hollies remained standing, but had their tops snapped off. The single shrub rowan was apparently crushed by a toppled tree. Only one coppice beech and five shrub hollies appeared to have avoided serious damage from falling trees and debris.

Despite the devastating damage and the description of a few fallen crowns as dead/dying, most standing and toppled trees remained alive in 1988. Immediate deaths included only three individuals, a snapped coppice and small self-sown beech and the windsplit pollard beech, although some lower strata individuals that were crushed beneath the fallen trunks and crown debris and failed to resprout could easily have been overlooked. Fallen crowns covered a major part (23%) of the of the transect, and combined with the abundant fallen trunks and lower branches to shade much of the ground. Nevertheless, several patches of fully-lit ground occurred between the ranks of fallen trees.

A year after the storm new regeneration appeared limited to a group of birch seedlings to 40cm height that occupied a $10m^2$ block; seven beech seedlings on root mounds or the edges of associated hollows; and there were three scattered holly seedlings. Some of these beech and holly were possibly surviving advance regeneration, and this appeared to be the case for four groups of small holly seedlings/suckers, two sets of basal growth from old pollard holly snags, and seven

patches of low suckering growth found around surviving or bent over hollies. Regenerating individuals that appeared to have been reduced by the storm amounted to; five damaged beech coppice stools with basal regrowth from 50-120cm height; two sets of sprouting beech root with short sprouts that had been left in the ground when the associated pollard was windthrown; and the crushed rowan was presumably sprouting. Two oaks showed signs of regrowth: the large standard oak had many epicormics present where the upper branches had been windsnapped, and the windblown 38cm d.b.h. oak tree had 25-30cm long epicormics all up the trunk. In the ground flora two small bramble recruits were plotted.

Stand condition 4 years after the 1987 storm

The records made in 1992 were mainly descriptive, but contained some details on tree mortality. Most fallen trees were reported as dead, in an advanced state of decay, and with decaying fungi present. In fact, 7 out of 14 windthrown beech had died, 5 pollards and both trees. Two windthrown beech pollards and a windthrown oak trees given as dead were certain errors, and the state of decay of the trees was exaggerated. Otherwise, one fallen oak was recorded with epicormic growth.

Regeneration had occurred throughout the transect. It had been especially abundant in open areas, where vigorous growth of birch to a density of 15 individuals per m^2 had been achieved. Otherwise, holly patches had increased notably in area and height. The ground flora had developed too, with willowherb and foxglove dominant, and growth of hard fern apparent around the base of root pits. Some of the lifted root plates had started to deteriorate, with heavy rains blamed for recent erosion.

Otherwise, there had been some disturbance when a foot path that originally crossed the transect was reinstated: a windthrown beech pollard had its top cut off, and other material, ground vegetation and regeneration had apparently been cut, cleared or moved to the path edge.

Stand condition 11 years after the 1987 storm

The 1999 recording came eleven growing seasons after the 1987 storm struck and ten growing seasons after the 1988 recording. By this time many larger trees had died (Table 3): 10 out of 12 windthrown/ snapped beech pollards; both larger beech trees and the smaller oak that were windthrown; and 2 out of 5 beech pollards that remained standing after the storm but suffered major crown loss. In addition both of the smaller bollings on the three-boled pollard individual which were windsplit or left standing with minimal damage had died. Some trees that died were located beside the reinstated footpath and had been cut with chainsaws: a windthrown beech pollard had its bolling cut through causing the root plate to slumped back; two beech pollards that had remained standing and suffered major crown loss had their remaining secondaries cut off; and the smallest bolling on the 3-boled beech pollard had most of the sprouts on the bolling top cut off. With the loss of many of the fallen large trees, the area of fallen live crown decreased greatly from 1988 to just 6% cover. The total would have dropped even further, except that at the transect start a post-1988 windblown beech fell into the transect and remained with a live crown in 1999.

Table 3: Fate of individuals recorded in beech wood pasture stand before the 1987 storm (see Table 1) eleven years later.

	Beech			Oak	Holly	Rowan
	Pollards	**Standards & other canopy trees**	**Coppice & small self-sown trees**	**Standards & other canopy trees**	**Shrubs**	**Shrubs**
Dead	12	2	7	1	-	-
Left standing with minor crown loss & now sprouting	1	-	1[(1)]	-	5	-
Left standing with minor crown loss & now windthrown	1	-	-	-	-	-
Left standing with major crown loss & now sprouting	3	-	-	1	-	-
Left windthrown & now sprouting	2	-	1	1	-	-
Left crushed, bent over or pinned & now sprouting	-	-	2	-	6	1
Left hit and snapped by other trees & now sprouting	-	-	2	-	2	-
Left hit and snapped by other trees but now not sprouting	-	-	2	-	-	-

[(1)] stool was felled when path was reinstated.

All five surviving large individuals that were left standing after the storm had started to sprout. On four surviving beech pollards, the remaining major secondaries still had poor crowns and few trunk sprouts, whereas the bolling tops and small broken secondaries had vigorous sprout growth, albeit that on one the secondaries had been badly debarked by squirrels and on another the lower side branch forks had been cut off. On two of the pollards vigorous basal/root sprouts had developed, and two with reliable measurements increment since 1988 had averaged 0.58cm and 0.65cm d.b.h. per year. On the oak standard that was left standing but with several snapped limbs still hanging, parts of trunk bark had died and the d.b.h. increment since 1988 had been negligible, but on the surviving forks and lower trunk sprouts had shot strongly. Thus, by 1999 total canopy cover had only increased slightly to 3%, with all five standing trees showing marginal increases in canopy area.

In addition, the three surviving trees that were windthrown in 1987 had all started to sprout. On the two fallen beech pollards, new erect vigorous sprouts had developed close to the bolling top on smaller secondaries (even though on one some have been sawn off), and even the large

secondaries remained alive, despite the upper bark sloughing, with some new crown sprouts and spreading laterals having developed. On the medium-sized windthrown oak standard most of the crown had been shattered by the fall, but numerous erect vigorous sprouts had developed along the crown forks, and several very vigorous sprouts that had the potential to form future trees had shot up near the trunk base. A further windthrown beech pollard had not sprouted: this had been toppled since 1988 when it was standing with minor crown loss, and much of upper crown had been sided-up along footpath to leave the remaining branches weakly alive and a few non-vigorous trunk sprouts.

Beech coppice and small self-sown trees suffered lower mortality than beech pollards and canopy trees: 47% compared to 67% loss. The seven dead individuals had all been struck and died: two immediately so and five others that failed to successfully resprout. By 1999 most surviving individuals had started to sprout; on two individuals apparently smashed in the 1987 storm, one had six main basal sprouts that were more-or-less vigorous and arching upwards, and the other had 2 out of 4 main sprouts developing upwards; on two three-stemmed stools, the first had two snapped stems that were being replaced by new vigorous leaders whereas the undamaged stem remained in the upper canopy layer with a mainly squat crown, and the second had two dead snapped stems and a third surviving shattered stem bent over at 4m with three vigorous sprouts 3m up; on a twin-stemmed stool that survived the storm with minor crown loss seven erect vigorous basal sprouts had managed to grow after being felled when the path was reinstated; and the five-stemmed windthrown stool had been reduced to two surviving stems with vigorous trunk sprouts at 2-4m along, although the crowns were mainly dead and smothered by bramble. Only two individuals failed to sprout noticeably: these were single-stemmed and had been bent over or snapped at 3-4m up.

All 13 holly individuals present before the storm had developed strongly from basal and root sprouts to form erect vigorous bushes, and the presumed crushed rowan had developed into a vigorous multi-stemmed individual.

Table 4: Regeneration in the beech wood pasture stand eleven years after the 1987 storm. Birch and holly were recorded in 0.078ha of the transect whilst other species were recorded in 0.194ha of the transect.

	Birch	Holly	Beech	Oak	Rowan	Willow	Rhodo-dendron
Regeneration alive ≥1.3m							
Newly established (n) [1]	701	29	3	2	1	1	-
Regrown from sprouts/suckers (n) [2]	-	2	13	2	1	-	-
Density individuals (n ha-1)	8987	397	82	21	10	5	-
Individuals alive <1.3m (n)							
Seedlings	1	1	4	1	2	-	1[3]
Root suckers	-	n.r.	-	-	-	-	-
Layers	-	1	1	-	-	-	-

n.r. = not recorded; [1] recruited since 1987 storm from seed origin except hollies which included many suckers and some advance regeneration; [2] from individuals present before and damaged by the 1987 storm; [3] origin unsure.

There had been copious new regeneration since 1988 but further substantial recruitment appeared unlikely (Table 4). Most recruits were of birch and holly and these were mapped in full in the first part of the transect. Other species were recorded along the whole transect, and the fate of all regenerants mapped in 1988 was checked.

In total 701 new birch saplings were mapped. Another 54 birch saplings were already dead, all but two of which had been excluded and were sized 2cm d.b.h. All of the new saplings were post-1988 recruits: the seedling group recorded in 1988 was not in the section mapped in detail in 1999 because they had largely been destroyed when the footpath re-instated. The most vigorous recruits must have established soon after 1988, and thereafter probably attained average increments of about 0.8-1.1cm d.b.h.per year and 1m height yr^{-1}. The d.b.h. size-class distribution of all recruits in 1999 was log-normal (Figure 1): most stems were <4cm d.b.h., overtopped and not vigorous, but a few potential canopy dominants had grown to >6cm d.b.h. and remained erect and vigorous. Some saplings across a wide range of sizes appeared to have been struck by branches or trunks snapped down off already windblown trees or off standing trees and snags. These saplings were either bent over or had the central leader damaged or killed off. Although many appeared to have been permanently relegated, some of larger stems were vigorously resprouting and may recover.

Birch saplings were noticeably clumped (Figure 2). They were most dense in areas that remained fully-lit after the storm, i.e. there were few saplings in areas covered by fallen trunks, crown debris, fallen live crown, thickets of holly regeneration, or where abundant ground vegetation had developed. The largest diameter saplings were concentrated along the edges of the main groups or were isolated individuals close to the dense bracken area (Figure 3), i.e. where competition was least and access to light high. Within the sapling groups the larger saplings were only moderately clustered. In due course the stand would be expected to close over, but this initial patchy distribution will remain.

Within the mapped section 29 holly recruits were recorded. At least seven of these appeared to have been present as low-growth before the storm, including two at the bases of old holly pollards. Some of the 24 one- to three-stemmed recruits could have been of seed origin but most appeared to be from sucker growth. Certainly the other three recruits with 4-8 stems and two recruits with 31-35 stems were dominated by sucker growth. Most recruits were erect and vigorous, part of several discrete holly thickets, and had a conservative distribution which presumably reflected conditions in the stand prior to the 1987 storm (Figure 2).

Beech had recruited only three new saplings in the whole transect; two that had grown since 1988, and one which was the only surviving seedling of the seven mapped in 1988. A fourth new individual established with 3 erect vigorous stems from the root nodules of a pollard that were left in situ when the bolling was windthrown. Otherwise, four new beech seedlings had established; three at 50-100cm height and another which was browsed off at 30cm height. An interesting development was the initial layering of a 17.5cm d.b.h. beech stem that had been snapped over into the transect, although the few branch end layers had not developed any erect vigorous sprouts. Oak recruited two spindly saplings of about 1.5m height, one of which was overtopped in a birch thicket whilst the other was in the open emerging from between some fallen beech trunks. A single erect vigorous rowan sapling had grown to 5cm d.b.h. and 10m height, and one spindly willow sapling had got to 1cm d.b.h. Otherwise, one spindly oak seedling at 85cm height, two rowan seedlings at 1.1-1.2m height, and a small rhododendron bush on a windthrown beech root plate established.

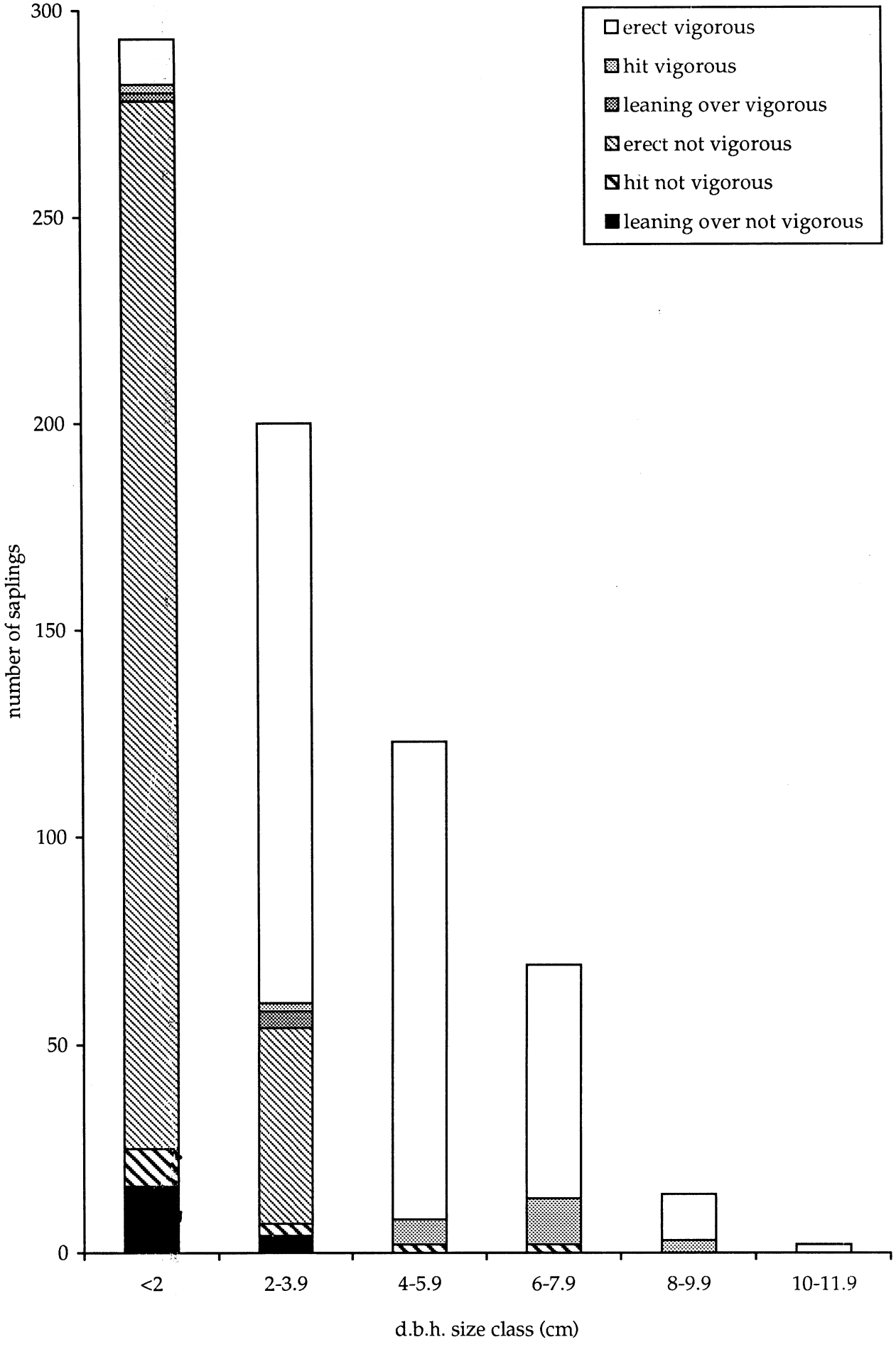

Figure 1: Size-class distribution and status of birch saplings recorded in 1999. Multi-stemmed and forked saplings are based on the largest sized stem.

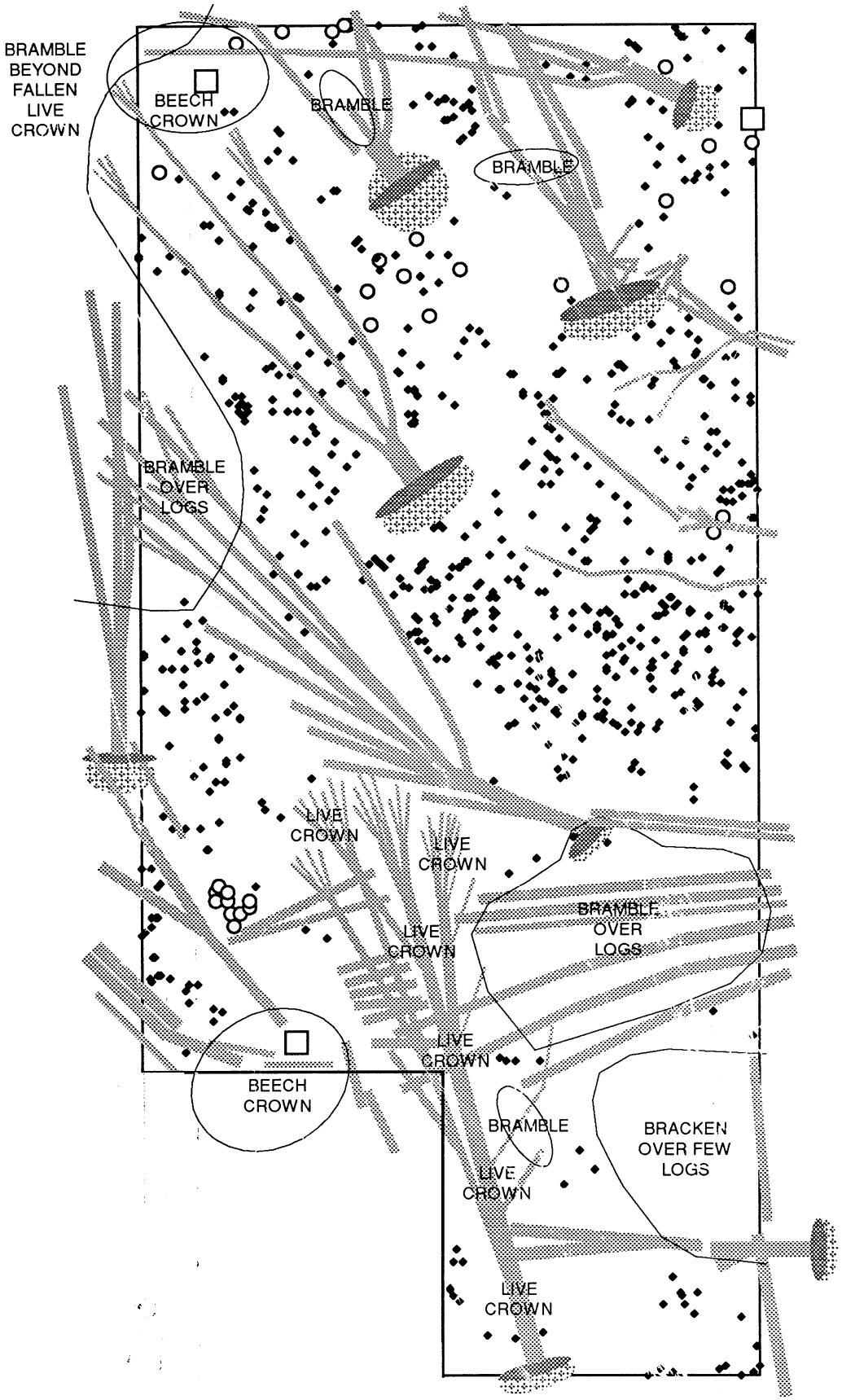

Figure 2: Distribution of regeneration, surviving and fallen trees, and ground vegetation in the transect section in 1998. Birch (diamonds) and holly (circles) regeneration, surviving beech (large squares) and their canopy cover, fallen trunks and associated root plates and hollows (hatched) and remaining areas of live canopy, and patches of ground vegetation and the dominant species are shown.

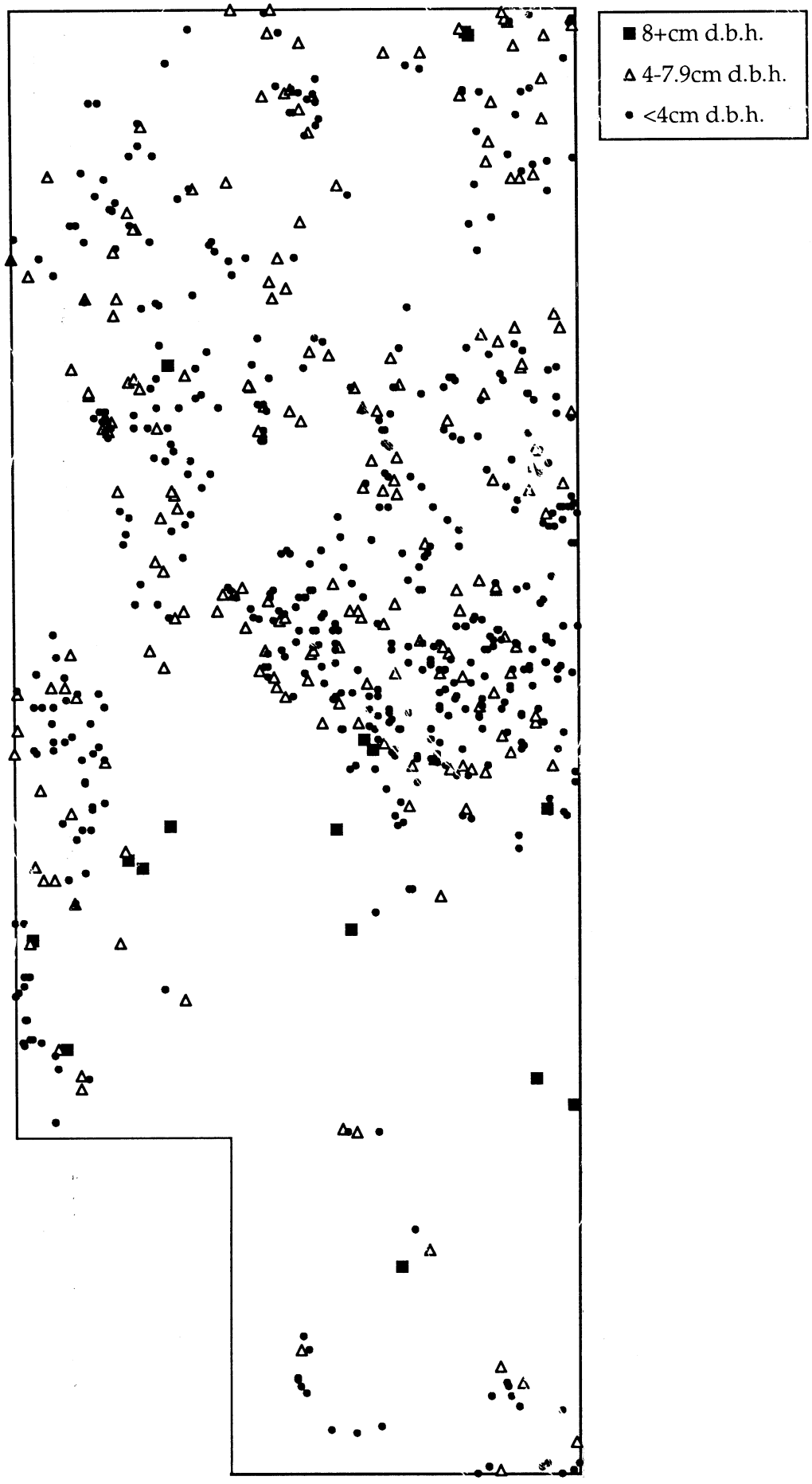

Figure 3: Distribution of birch saplings in a sample section of the beech wood pasture transect in 1999. Each sapling is shown according to three d.b.h. size classes.

Fallen trunks and crown branches were still abundant and in a few places they lay stacked upon each other in an impassable mass (Figure 2). The large dead fallen bollings and trunks had little decay and some or much bark left, whereas dead fallen secondaries and crowns branches were beginning to decay, had lost most twigs, and had little bark left. Many root plates had part- or mostly slumped, infilling much of the associated hollow or even creating a soil mound, but a few remained more-or-less intact. Fallen dead wood volume was not measured directly but fallen trees were sketched and an estimate of its volume can be derived. There were twelve snags >5cm d.b.h. within the transect; five beech bollings at 35-90cm d.b.h.; five snapped beech coppice trunks at 6-15cm d.b.h.; and two holly trunks at 6-10cm d.b.h. These generated 30.5m^3 ha^{-1} volume of standing dead wood, virtually all of which was within the five large, 1.5-3.5m tall, part-decayed beech bollings. On this basis, the fourteen fallen beech bollings within the transect would have created >400m^3 ha^{-1} dead wood volume, and the total volume would have been around 500m^3 ha^{-1}, not an unreasonable value for a collapsed old-growth stand (Jones 1945).

The ground flora developments reported in 1992 had changed considerably. Instead of willowherb and foxglove, bramble and bracken were now dominant. Several patches of dense sprawling bramble had grown over areas covered mostly by fallen dead crown debris, and in one place dense bracken had developed over an area with few logs (Figure 2). In all places where the ground vegetation remained abundant, birch regeneration had not developed strongly and certainly bramble was being shaded below areas where the birch canopy had closed. Hard fern was abundant around the hollow of one windthrown beech pollard.

The stand condition outlined above was repeated before and in the next transect section and elsewhere in the area, save for a 2m-wide swathe that was destroyed when the footpath was reinstated.

Discussion

Storm-damage is a major disturbance factor in many temperate woodland areas (Falinski 1978; Bormann & Likens 1979; White 1979; Schaetzl *et al.* 1989; Runkle 1990), including the oceanic fringe of north-west Europe (Koop & Hilgen 1987; Van Den Berge *et al.* 1990; Emborg, Christensen & Heilmann-Clausen 1996, Peterken 1996; Pontailler, Faille & Lemee 1997). Indeed, storms here have apparently influenced forest dynamics for millennia (Allen 1992). Although woods in south-east England were far from natural, the continued importance of this factor is exemplified by impact the Great Storm of October 1987 (Grayson 1989; Whitbread 1991; Kirby & Buckley 1994; Peterken 1996). The transitions reported here clearly show how important one extreme short-term event can be in woodland development.

Although the study transect provided only a small example of changes at Toy's Hill, a walk through the surrounding plateau stands revealed that similar changes were widespread. Prior to the 16 October 1987, the plateau supported an impressive old-growth stand dominated by outgrown beech pollards. Within one night around 50ha of this century-old stand were virtually levelled by the exceptional storm that swept across south-east England with gusts in excess of 100 m.p.h. (Burt & Mansfield 1988). The storm was an intense phenomena, the likes of which had probably not been seen in this region for 200 years (Burt & Mansfield 1988), but the peak gusts typically lasted only two to three hours at any one location. Apparently it was just such a series of gusts at Toy's Hill that left most of large canopy trees uprooted within a 90° arc, 5% of the ground upturned, most of the few remaining standing trees with broken crowns, and most

understorey trees broken, snapped and/or crushed. Hutton (1989) gave >90% storm damage over most of the plateau and its upper slopes.

Despite the severity of this storm and the total amount of damage caused by the storm, the pattern of damage on the ground was extremely patchy with relatively few large-scale blow downs as recorded at Toy's Hill (Whitbread 1991; Allen 1992). However, the plateau woodland at Toy's Hill was vulnerable to the effects of such an intense storm: it grew on an exposed high plateau, had shallow soils, and was dominated by large-sized and heavily branched outgrown beech pollards that offered a high wind resistance and shallow-rooting capabilities, as revealed by the abundance of thin, hinged root plates (Allen 1992).

In the decade following the storm some further windblow occurred, with more beech trees added to the mass of fallen trunks. Despite the early survival of downed trees, there was a decline in the area of fallen live crown and a surge in dead wood as most of these and the standing survivors died off. This left an enormous $500m^3\ ha^{-1}$ dead wood volume estimate, but even within a decade there were already some signs of decay setting in and within 30-40 years much of this will have probably rotted away (Van Hees & Clerkx 1999).

Several observers predicted that windblown beech would progressively die off following the storm (Whitbread 1991), and this was largely the case within the Toy's Hill transect. On both fallen and standing survivors there was little sign of vigorous crown expansion. Rather redevelopment on these has been mainly as pollard- or coppice-type growth: beech pollards were sprouting mainly at or near to the bolling top; standing large oaks were shooting along the crown forks and up the lower trunk; and windthrown oaks had numerous erect vigorous sprouts especially near the base. Survival was generally better in smaller individuals, with about half the original beech alive a decade later and redeveloping from basal or trunk sprouts.

A few birch were left standing beyond the transect and evidently broadcast seed across the site to produce thickets of birch regeneration in areas away from piles of fallen trunks and crowns, ie as would be expected on exposed bare ground with no ground vegetation competition and shading (Miles 1973; Kinnaird 1974). The original small holly clumps regrew vigorously, but there was little recruitment of other species, despite 1987 being a moderate mast year for beech and oak (Evans 1988; Hilton & Packham 1997). This pattern of vigorous birch groups and holly regowth was prevalent in many storm-damaged beech-oak woods (Whitbread 1991).

Within the study transect, there was a temporary surge in willowherb and foxglove onto what had been virtually un-vegetated ground covered with leaf litter before the storm (Hutton 1989): these are both characteristic invaders of bared acid soil in well-lit conditions (Grime, Hodgson & Hunt 1988). Within about five years these had been largely shaded out by the new birch thickets or patches of bramble or bracken (Parker 1993). In addition, bramble had spread over many of the areas covered by dead crown debris forming apparently semi-permanent features. Root plates generally slumped and part-infilled the hollow behind, but a few remained more-or-less intact and continued to support hard fern, indicative of the type of discrete ground vegetation that was recorded around root plates at other storm-damaged woods (Buckley, Bolas & Kirby 1994).

Not all parts of Toy's Hill were left to develop naturally after the storm. The scene of devastation prompted outcries and the launch of government-funded incentives to 'repair the damage done' (Countryside Commission 1988; Forest Windblow Action Committee 1988). In this climate, it was decided to clear much of Toy's Hill by bulldozing and burning the windthrow, and then either

replanting or leaving the areas to natural regeneration. The clearance compacted the soil, encouraged erosion, drastically reduced the amount of fallen dead wood and crown debris, and hence encouraged the widespread establishment of dense birch thickets (King 1994). It is now clear that woodland regeneration has established well in areas left to natural development, and that here the small-scale mixture of habitats, including closed birch thickets, bramble-filled open-spaces, piles of decaying dead trunks and crowns, and the few sprouting pollards and trees and other native tree regeneration, represents a far superior wildlife habitat and at no cost.

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