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Monitoring natural stand change in Monks Wood National Nature Reserve

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Monitoring natural stand change in Monks Wood National Nature Reserve

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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. We hope that this will contribute to the long-term survival of the records, which, as the authors point out, is a major problem with long-term studies.

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 in unmanaged semi-natural stands in Monks Wood NNR between 1985 and 1996 were quantified by recording all stems within four permanent transects.

- These stands had long been treated as coppice-with-standards, principally penduculate oak over ash, field maple, hazel and hawthorn. They were virtually clear-cut in the 1920s and have since been allowed to grow without further silvicultural intervention.

- Changes between 1985-96 were typical of the stem exclusion stage of stand development. The canopy remained largely closed. Basal area increased. Living stem density decreased as the size of surviving stems increased. Smaller diameter stems tended to grow more slowly, occupy lower strata, show more dieback and suffer higher rates of mortality than larger stems. Recruitment remained low.

- Differences between the performance of the major woody species were apparent. Ash gained in importance through low mortality, fast growth, and increasing canopy dominance. Maple declined but remained abundant, with most remaining stems in the subordinate strata. Oak retained its place through growth and low mortality of individuals retained after the 1920s fellings. Hazel declined, despite continued rapid growth, due to high mortality of large and small stems and limited recruitment. Hawthorns collectively remained the most abundant understorey species through low mortality, but growth was slow.

- During the study period muntjac deer became numerous. They appeared to have (i) destroyed stems below <1.3m height, (ii) destroyed ash stems less than 10cm gbh, (iii) reduced surviving privet to below 1.3m height, and (iv) debarked lower trunks. The last was small-scale, but loss of bark was especially severe on stems below 5cm gbh and particularly affected spindle, dogwood and privet stems.

- Most standing and fallen dead wood was small. Accumulations decreased after 1985 and volumes remained lower than in natural old-growth temperate forests. A pulse of mortality after the 1976 drought appeared to be passing rapidly through the system.

1. Long-term studies in woodland NNRs

Long-term observation of change in 'unmanaged' woodlands combines research and monitoring. Natural processes can be studied; environmental change can be detected; and, by comparison with managed stands, the ecological effects of forestry can be quantified. Woods assigned to non-intervention indefinitely are thus reference points, or controls, forming an essential scientific basis for nature conservation. In the United States, such places are known as Research Natural Areas.

Unfortunately, long-term studies are difficult to sustain. Most potentially long-term studies fall prey to human failings before they become long-term. Initiators lose interest or get promoted. Fashions in science and conservation change. Records are lost or forgotten. Institutions are reformed or disbanded. Financial support is fickle. Even those woodland studies that have lasted 25 years or more have done so by the skin of their teeth (Peterken and Backmeroff 1988).

During the 1980s, Christa Backmeroff and GFP re-recorded several permanent plots and transects in unmanaged woodland reserves, and established new transects in several others (Peterken and Backmeroff 1988). This was part of the NCC programme of scientific research managed by the Chief Scientist's Directorate. The aim was to establish a set of long-term reference studies in England, Wales and Scotland, and the individual reports and records were lodged with NCC. Christa Backmeroff also searched scientific files of most woodland NNRs for old observations which could usefully be repeated and thereby become long-term studies; the outcome was disappointing, but the limited results were reported (C.E. Backmeroff, unpublished reports). Shortly after, records of observations made in woodland NNRs in the 1960s by R.C. Steele and others became surplus to requirements on his retirement, and were 'rescued' by GFP. Subsequently, these records were retained by GFP when he left JNCC in late 1992, at that time there being no scientific archive within the NCC successor bodies.

Two opportunities have since arisen to use these records to study changes in Monks Wood NNR:

- In 1996, Ariane Crampton and Oliver Stutter, both students on the M.Sc. Forestry course at Oxford University, used the 1960 records made by R.C. Steele to study change in the ground vegetation and stand structure. The immediate outcome was dissertations in part-fulfilment of the degree requirements, but publication of the results is also intended (Crampton 1996; Stutter 1996). English Nature gave advice and logistical support, together with records copied from GFP.

- In 1996, the transects established by Christa Backmeroff were re-surveyed by EPM. This formed part of the RENFORS project (REgeneration of Native FORest Stands for timber production and environmental value) funded by the European Communities Directorate-General for Agriculture as a collaborative project between teams in Sweden, Denmark, Italy and Great Britain (Contract FAIR PL95-0420). This project specifically intends to; (i) identify the variables that control the species diversity of trees and forest flora and fauna (biodiversity) at the regeneration phase; (ii) develop silvicultural measures that favour biodiversity at the regeneration phase; (iii) experimentally test measures in traditionally managed mature stands; and (iv) analyse the economic and biodiversity implications of the systems developed.

The records of the initial condition were included in a report to NCC by Christa Backmeroff, copies of which are held by English Nature. A copy of the 1996 records and analysis will also be lodged with English Nature. Copies of both recordings and analyses are held by GFP and EPM.

2. Description of Monks Wood NNR

Situation, status & history

Monks Wood (national grid reference TL 200800) is a 157 hectare woodland situated 10km north-east of Huntingdon, Cambridgeshire. The site is owned by English Nature (The Nature Conservancy Council for England) and, as one of the most important woods in the English lowlands, was declared a National Nature Reserve (NNR) in 1953/4. The wood is also famous because it is situated beside Monks Wood Experimental Station (now operated by the Institute of Terrestrial Ecology) and, following on from a period of thorough survey, a detailed account of the reserve was published in Steele and Welch (1973).

Monks Wood is classified as ancient and semi-natural, and, although containing areas of originally cultivated land, is considered to be a reasonable remnant of the original ash-oak woodland on clay that was typical of much of lowland England. Traditionally the wood was treated as coppice-with-standards, but between c.1915-20 was extensively felled, except for a scatter of ash and some oak, and left to naturally regenerate. During the 1950s coppice management was reintroduced in some selected areas, but the remainder has been retained under a non-intervention regime (figure 1) (Massey 1994).

Topography, geology & soils

The southern part of Monks Wood lies on the edge of a relatively flat plateau and is underlain by Chalky Boulder Clay that gives rise to moderately well drained, brown, calcareous, clay loams. The wood then descends across slopes of 3-4° into a flat, low-lying, central and northern area. This area is mostly underlain by Oxford Clay with some Loamy and Sandy Drift material occurring especially along the north-west boundary of the wood. Drainage here is typically poor and the clay soils are mainly grey, calcareous, surface water gleys.

Vegetation

Most of Monks Wood conforms to Peterken (1993) stand-type 2Aa Wet ash-maple woodland, together with a few patches of stand-type 10A Invasive elm woodland. Both of these are contained within W8 *Fraxinus excelsior-Acer campestre-Mercurialis perennis* woodland of the National Vegetation Classification (Rodwell 1991).

In much of the wood ash (*Fraxinus excelsior*) is dominant in the canopy, while field maple (*Acer campestre*) is also widespread and often co-dominant, and pedunculate oak (*Quercus robur*) is scattered as a residual standard tree. Minor trees include scattered birches (*Betula pendula/pubescens*) and wild service (*Sorbus torminalis*), localised stands of smooth-leaved elm (*Ulmus carpinifolia*), and aspen (*Populus tremula*) and sallows (*Salix caprea/cinerea*) in wetter areas.

The understorey is typically well developed and mostly of hazel (*Corylus avellana*), and both pure and hybrid midland hawthorn (*Crataegus laevigata*) and common hawthorn

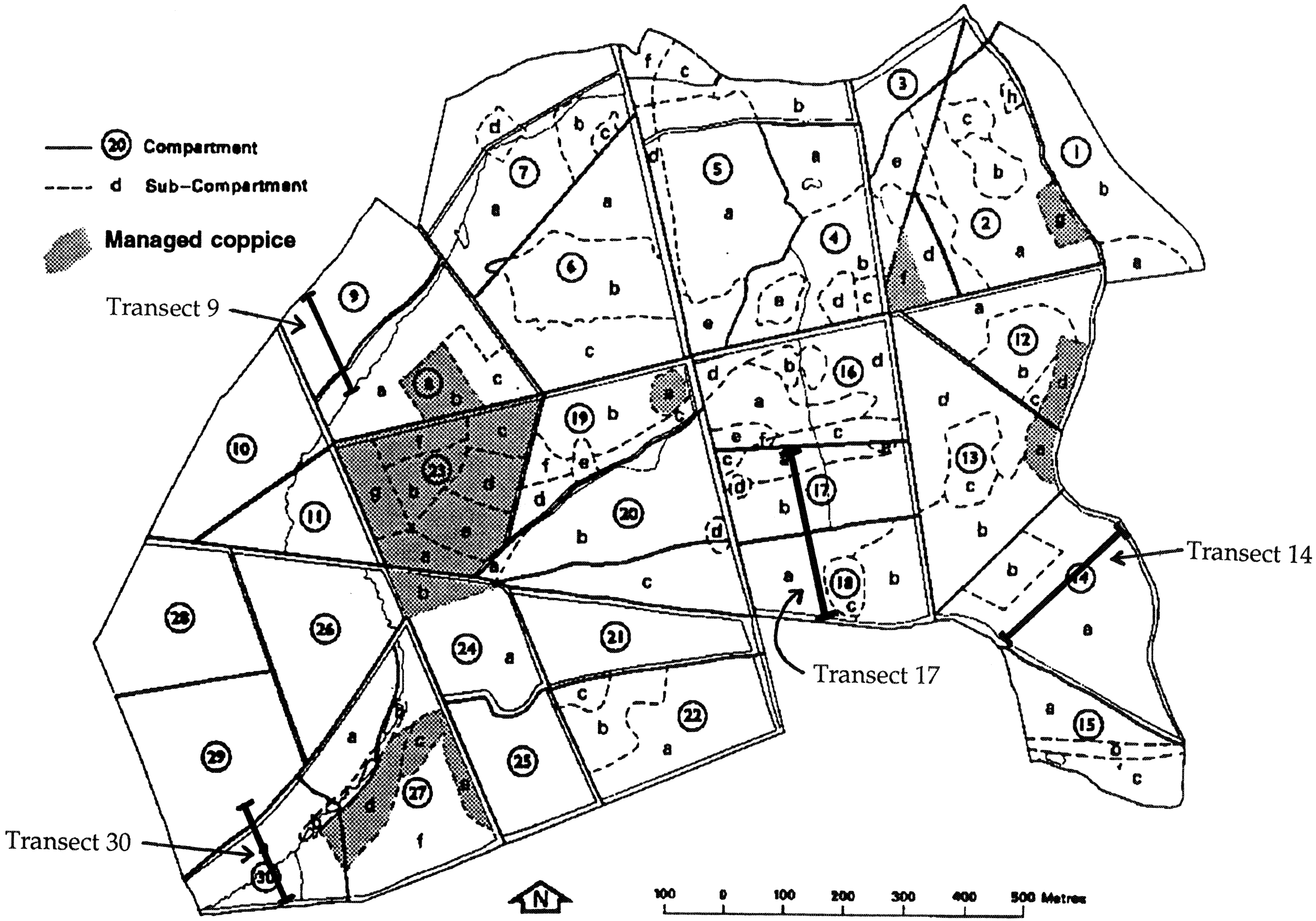


Figure 1: Management map for Monks Wood (taken from Massey and Welch 1994). Apart from the areas of coppice, non-intervention is prescribed. The four permanent long-term monitoring transects are shown.

(*Crataegus monogyna*). In addition several other understorey species occur including, blackthorn (*Prunus spinosa*), crab apple (*Malus sylvestris*), dogwood (*Cornus sanguinea*), privet (*Ligustrum vulgare*), elder (*Sambucus nigra*), spindle (*Euonymus europaeus*) and guelder rose (*Viburnum opulus*). Occasional climbing roses (*Rosa* spp.) and honeysuckle (*Lonicera periclymenum*) are encountered.

In the ground vegetation dog's mercury (*Mercurialis perennis*) and bramble (*Rubus fruticosus* agg.) can be dominant on better drained soils, together with herbs such as ground-ivy (*Glechoma hederacea*), enchanter's-nightshade (*Circaea lutetiana*), wood avens (*Geum urbanum*), bluebell (*Endymion non-scripta*), primrose (*Primula vulgare*), wood anemone (*Anemone nemorosa*) and lesser celandine (*Ranunculus ficaria*).

The vegetation of the wood has change considerably in recent decades in response to a series of natural, semi-natural and managed events (Massey and Welch 1994). However, increased browsing by Chinese muntjac (*Muntiacus reevesi*), a highly selective introduced deer, has become particularly important since their population boomed in the mid-1980s (Cooke 1994).

3. Recording and Analysis Methods

Study data

The baseline record for long-term monitoring at Monks Wood was carried out by Christa Backmeroff between June-August 1985. Along four 20m wide transects (figure 1), covering 1.7ha, and located and numbered in four non-intervention compartments (Steele and Welch 1973), the exact location of all trees and shrubs were mapped. The following data was recorded on scaled charts that covered 30m long transect sections (Backmeroff 1985):-

- the species and status (as standing alive >1.3m height, fallen alive >1.3m height, standing alive <1.3m height, or dead) of all individuals attaining 1.3m height and all established seedlings <1.3m height (NB: some individuals <1.3m height were simply aggregated in 'seedling groups')
- the girth at breast height 1.3m (gbh) of all living and dead stems attaining 5cm gbh and many <5cm gbh, measured to the nearest cm using a tape
- the orientation of leaning and fallen stems
- sketches of the position of fallen dead logs (criteria not specified)
- the location of salient features such as streams and rides

Between 17th October-11th November 1996 the transects were resurveyed and the following data collected:-

- the species and status (as standing alive >1.3m height, fallen alive >1.3m height, standing alive <1.3m height, or dead) of all stems attaining 1.3m height and all established seedlings; surviving stems and recruits were noted
- the girth at breast height 1.3m (gbh) of all living stems attaining 3cm gbh, except for privet which was measured at ground level, and all dead stems attaining 5cm gbh, to the nearest 0.5cm using a tape
- the crown position of all living stems >1.3m height defined according to four stratificatory layers; *canopy* (in uppermost layer and not overtopped), *sub-canopy* (just below and mostly overtopped by the canopy layer), *understorey* (below sub-canopy layer), or *ground* (mostly below 2m height)
- the crown size of all living stems >1.3m height defined relative to the canopy position, potential for the species, and according to four categories; *large*, *medium*, *small*, or *very small*
- the extent of visible crown dieback for all living stems >1.3m height defined relative to crown size and according to a five-point scale; *very severe*, *severe*, *moderate*, *part*, or *none*
- the extent of lower trunk debarking (recent and old) to all living stems >1.3m height defined according to a four-point scale; *severe* (>50% bark removed), *moderate* (10-50% bark removed), *limited* (<10% bark removed), or *none*
- the approximate height and a description of the decay state (as solid, part rotten, rotten or very rotten), amount of residual bark (as percentage on whole stem), and remaining branches and twigs, for all dead stems >1.3m height

- the position of larger fallen dead logs attaining 15cm diameter at largest end and 2m length with notes on their origin and state of decay
- the quantity and quality of fallen dead wood using the line transect method of Warren and Olson (1964); twenty-seven 20m long line transects were positioned across the middle of each 30m long transect section; the diameter or girth (to nearest cm) of fallen dead stems attaining 5cm diameter where they crossed the line were measured with a tape, together with the degree of rot (as solid, part rotten, rotten or very rotten along the whole stem), amount of residual bark (as percentage on whole stem) and probable source of origin
- the vertical position of canopy gaps as viewed from the ground and notes on their disturbance origin and understorey infilling

Analysis procedure

The data set provided a large volume of information concerning over 9500 stems. To facilitate sorting and analyses the data was put on to a Microsoft Excel spreadsheet. Statistical testing was based on Zar (1984) and the analysis tools in Microsoft Excel.

In most situations the recorded data appeared unambiguous and the problems that did arise were mostly associated with complex, multi-stemmed and forked hazels and hawthorns, where stem relocation and gbh measurements proved problematic. In a few instances obvious errors in stem status or gbh recording had occurred. In dealing with errors small gbh reductions or possible large increases were not adjusted for, but otherwise errors were resolved by assuming reasonable change based on the performance of like stems. All assumed changes were disregarded from stem growth rate analyses.

The volume and length of dead wood from the line transect survey was determined using the formula given by Warren and Olson (1964):-

$$L = [(\pi \times N)/(2 \times l)] \times 10000$$

$$V = [(\pi^2/8l) \times \Sigma(n \times d^2)] \times 10000$$

where:-

L = estimated fallen dead wood length ($m\ ha^{-1}$)

N = total number of recorded stems

l = total transect length (m)

V = estimated fallen dead wood volume ($m^3 ha^{-1}$)

n = number of stems in each diameter class *

d = mid-class diameter (cm) *

* using seven 5cm classes from 5-9.9cm to >60cm

The method requires that a random set of transect lines are employed, but in this study lines were laid out at regular intervals to facilitate relocation. However this regular selection was not determined with any bias and was considered to provide a representative sample.

To calculate annual rates of change a study period of 11 years was decided upon. Stems <5cm gbh in 1985 were scored as 3cm gbh for basal area calculations. Although midland hawthorn and common hawthorn freely hybridise in the wood, all individuals were designated to a species according to the prominence of leaf shape characteristics.

Time and costs

The 1996 field work was mostly undertaken by two recorders working together. It took 32 person-days based on 8 hours per day. A further 35 person-days were required to input the data on to a spreadsheet, carry out all analyses, and write and produce the report. Additional costs were for travel, subsistence and measuring equipment.

4. General Changes in Stand Structure and Composition

Canopy Gaps in 1996

Transect & section number	*% gap*	Transect & section number	*% gap*
9:1	*11.2*	17:1	*5.5*
9:2	*5.0*	17:2	*13.6*
9:3	*10.3*	17:3	*3.7*
9:4	*3.0*	17:4	*16.7*
9:5	*6.5*	17:5	*18.0*
9:6	*10.2*	17:6	*18.2*
9:7	*10.3*	17:7	*9.1*
14:1	*6.6*	17:8	*22.2*
14:2	*2.4*	17:9	*69.1*
14:3	*0.8*	30:1	*2.3*
14:4	*2.7*	30:2	*3.8*
14:5	*1.2*	30:3	*13.8*
14:6	*4.9*	30:4	*3.9*
14:7	*4.0*	30:5	*0.0*
14:8	*1.1*	30:6	*10.5*
14:9	*0.0*	ALL	*9.5*

Table 1: Canopy gaps in 1996.

In 1996 fifty-five separate canopy gaps, covering 9.5% of the whole transect area, were identified (table 1; figure 2). Virtually all of these were filled below by understorey growth. Many were relatively small scattered patches caused by the death, windblow, crown dieback or windsnap of either ash or maple stems. Several others were due to the death of large birch trees, thought to be as a result of the 1976 drought.

Gaps were largest along transect 17. Those between sections 5 and 6 were connected with recent felling work to Dogwood path, when the path was partly realigned. The origin of the other large gaps was ambiguous, but they appeared to be relatively old and were associated with large dead stumps that were not recorded elsewhere on the transects. The very large gap at the end of transect 17 adjoined Aspen path and could have been subject to ride-edge management in the past that removed canopy-forming stems.

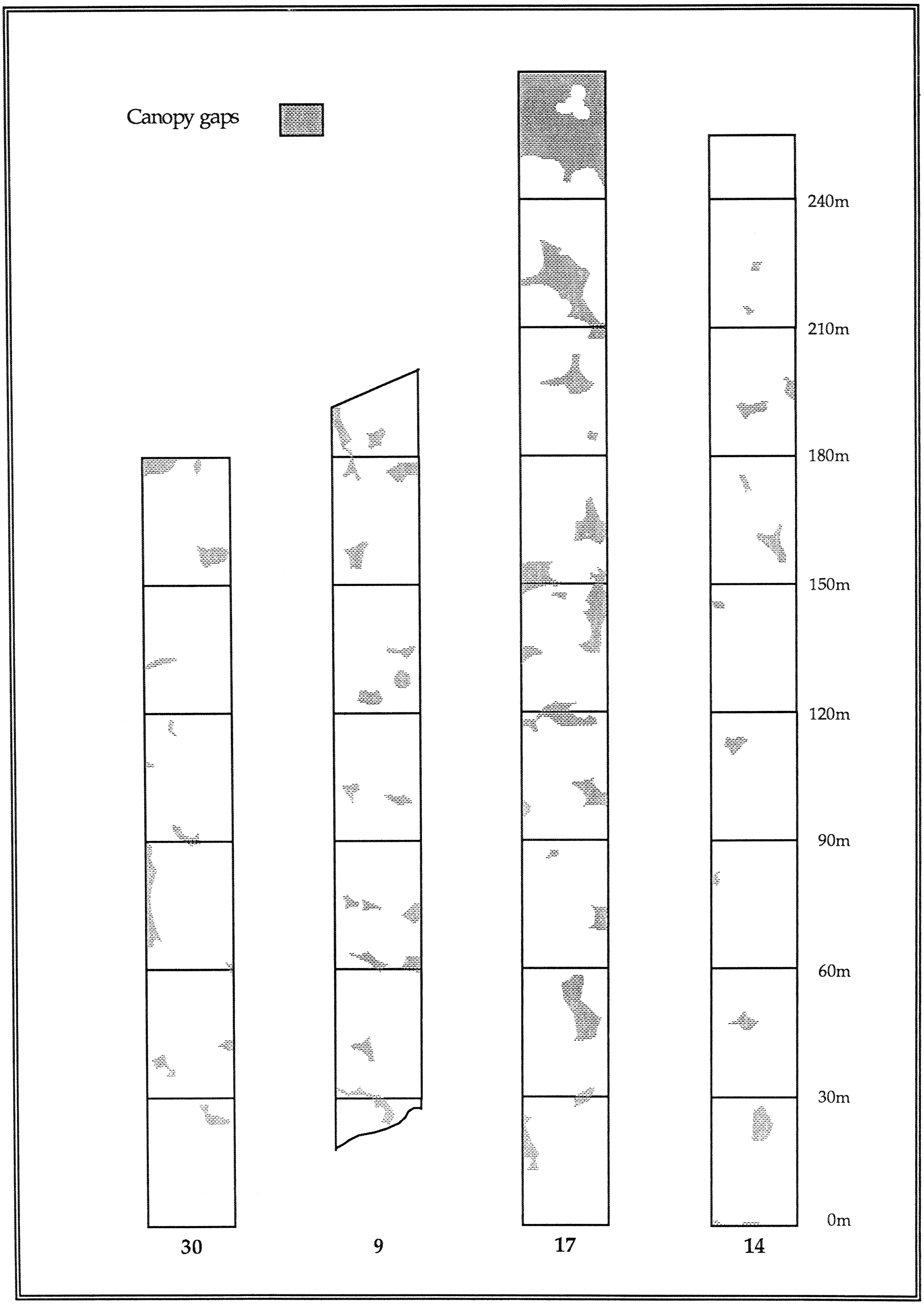


Fig 2: Location of canopy gaps along the permanent transects in 1996. The diagram is schematic (see figure 1 for true location) but the transects and gaps are to scale. Each transect number is shown below and the distance along to the right.

Change in basal area of stems alive >1.3m height 1985-96

	1985 $m^2 ha^{-1}$	1996 $m^2 ha^{-1}$	Change $m^2 ha^{-1}$
Major tree species			
Ash	14.6	17.3	+2.7
Maple	5.7	5.4	-0.3
Oak	2.9	3.1	+0.2
Minor tree species			
Sallow	0.2	0.1	minimal
Service	0.2	0.2	minimal
Birch	0.1	0.1	minimal
Aspen	<0.1	-	lost
Major understorey species			
Midland hawthorn	1.6	1.9	+0.3
Hazel	1.3	1.2	minimal
Common hawthorn	1.2	1.4	+0.2
Minor understorey species			
Blackthorn	0.3	0.2	minimal
Crab apple	0.1	0.1	minimal
Dogwood	0.1	<0.1	minimal
Privet	<0.1	<0.1	minimal
Elder	<0.1	<0.1	minimal
Spindle	<0.1	<0.1	minimal
Guelder rose	<0.1	-	lost
Other woody species			
Rose	<0.1	<0.1	minimal
Honeysuckle	<0.1	-	lost
Bramble	<0.1	<0.1	minimal
Total	**28.1**	**31.0**	**+2.9**

(calculated using all recorded stems standing or fallen alive >1.3m height in 1985 and 1996)

Table 2: Change in basal area ($m^2 ha^{-1}$) of stems alive >1.3m height between 1985-96.

The total living stem basal area increased by 10% from 28 to 31 $m^2 ha^{-1}$ between 1985-96, giving an annual rate of 0.3 $m^2 ha^{-1}$ (table 2).

Ash increased in dominance as the main canopy species as its allocation of the total basal area rose from 52 to 56%. Otherwise in the canopy, maple notably declined in basal area, whilst oak slightly increased and most others showed minimal change.

Hazel, midland hawthorn and common hawthorn remained as the main understorey species, but while the basal area of hazel declined minimally, both of the hawthorn species increased. The remaining species accounted for very little of the total basal area and showed minimal change.

Change in density of stems alive >1.3m height 1985-96

	1985 n ha^{-1}	1996 n ha^{-1}	Change n ha^{-1} annum^{-1}	Change %
Major tree species				
Ash	537.6	421.8	-10.5	*22*
Maple	240.0	207.1	-3.0	*14*
Oak	25.3	21.8	-0.3	*14*
Minor tree species				
Sallow	12.4	10.0	-0.2	*10*
Birch	11.8	4.7	-0.6	*60*
Aspen	3.5	-	-0.3	*100*
Service	1.8	1.8	0.0	*0*
Major understorey species				
Midland hawthorn	1139.4	1086.5	-4.8	*5*
Hazel	1075.3	755.9	-29.0	*30*
Common hawthorn	416.5	390.6	-2.4	*6*
Minor understorey species				
Privet	140.0	39.4	-9.1	*72*
Blackthorn	101.2	64.1	-3.4	*37*
Dogwood	96.5	31.8	-5.9	*67*
Elder	9.4	8.2	-0.1	*13*
Spindle	5.9	2.9	-0.3	*51*
Crab apple	4.1	3.5	-0.1	*15*
Guelder rose	4.1	-	-0.4	*100*
Other woody species				
Rose	10.6	7.6	-0.3	*28*
Honeysuckle	1.2	-	-0.1	*100*
Bramble	12.4	0.6	-1.1	*95*
Total	**5833.9**	**3058.2**	**-252.3**	***48***

(calculated using all recorded stems standing or fallen alive >1.3m height in 1985 and 1996)

Table 3: Change in density (n ha^{-1}) of stems alive >1.3m height between 1985-96.

The total living stem density decreased by almost by half, from about 5800 to 3000 stems per ha, between 1985-96, representing a decline rate loss of about 250 stems per ha per annum (table 3). Amongst the major tree species ash numbers declined the most, but its allocation of the total stem density still increased from 9 to 14%. Amongst the minor tree species, birch declined rapidly and aspen died out, whilst sallow and service changed little.

In the understorey the three major species all increased their percentage of the total stem density, with midland hawthorn rising from 19.5 to 35.5%, hazel from 18 to 25%, and common hawthorn from 7 to 13%. Nevertheless the hawthorn species both declined much less than hazel, which had the highest overall loss rate of any species. Amongst the remaining species guelder rose and honeysuckle died out, whilst privet, dogwood and bramble declined by high percentages.

Change in relationship between stem density and gbh for stems alive >1.3m height 1985-96

To examine the change between 1985-96 in the relationship between stem density and mean stem gbh for stems alive >1.3m height, 26 available transect sections were utilised (9.2-9.6, 14.1-14.8, 17.1-17.8, 30.2-30.4, 30.6 of area 600m^2; and 30.1 of area 592 m^2).

All sections showed a similar trend, with stem density declining logarithmically as mean gbh increased logarithmically (figure 3). This relationship was compared to that given for the self-thinning rule that relates declining plant density (p) to the mean biomass (w) of surviving plants by the power equation $w = Kp^{-1.5}$ (Yoda *et. al.* 1963; White 1981). Comparison using stem gbh measurements was justified as w α gbh (White 1981). The value of most change slopes fell within the -0.6 to -1.9 range, and of these the two lowest values both had high density values in 1985 and 1996. However 2 sections had exceptionally low slope values (-5.9 and -8.0), and although this indicates that thinning had been minimal, both had recruited a large number of hazel/hawthorn trunk stems or forks that were probably not recorded in 1985. In general therefore the data fits well with those expected by the self-thinning rule, with predicted -1.5 slope thinning occurring where stand density was highest and <-1.5 slope thinning occurring at lower stand densities (White 1981).

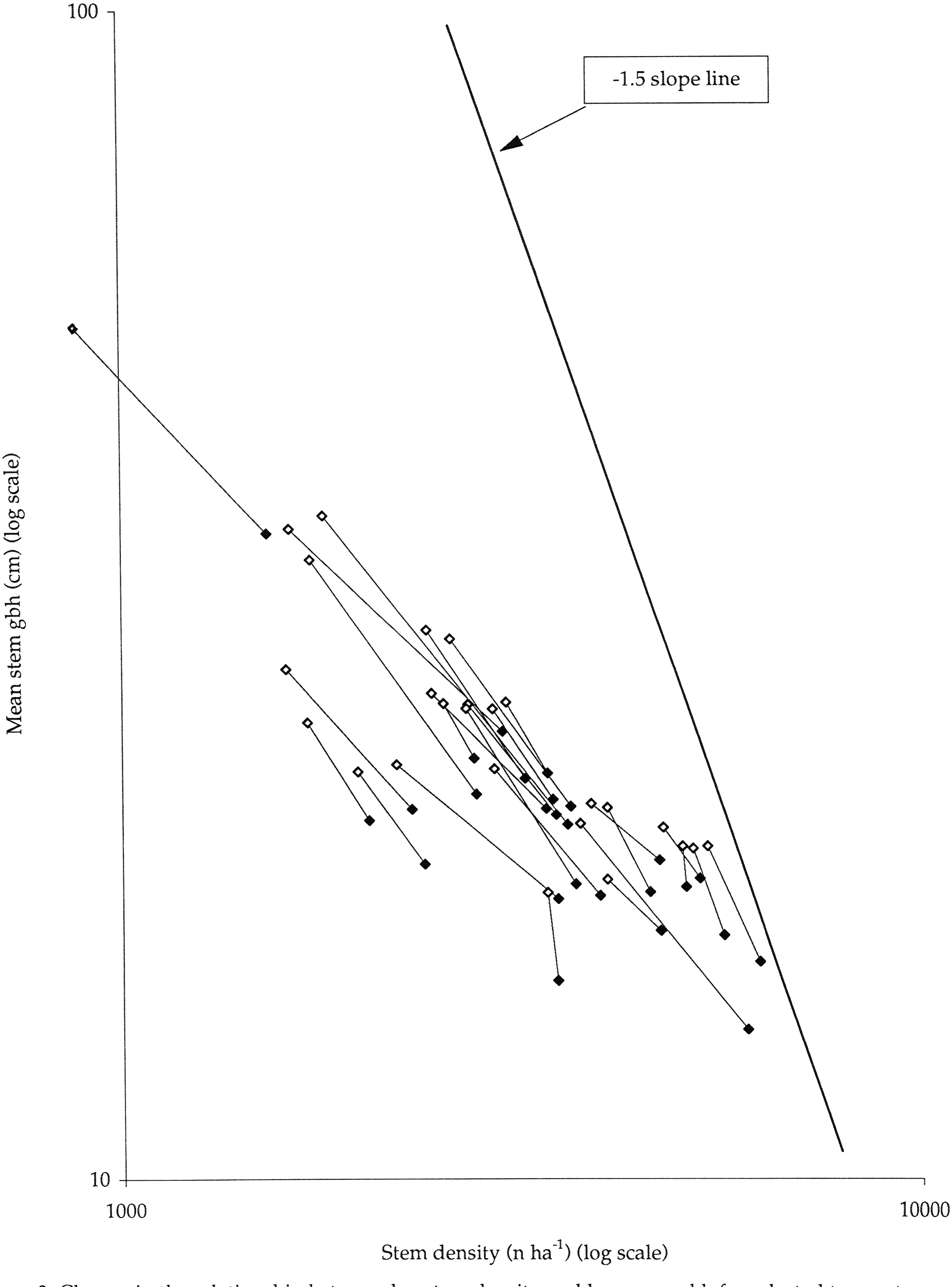


Figure 3: Change in the relationship between log stem density and log mean gbh for selected transect sections (see text for deatils) from 1985 (black diamonds) to 1996 (white diamonds).

5. MORTALITY AND RECRUITMENT

Fate and recruitment of stems alive >1.3m height 1985-96

	1985	Fate of 1985 stems by 1996				Recruitment 1985-96		
	Stems standing alive >1.3m	Standing alive >1.3m	Standing alive <1.3m	Fallen alive >1.3m	Died	All new stems standing alive >1.3m	New trunk shoots or forks	New individ-uals
	n	n	n	n	n	n	n	n
High survival/low loss								
Service	3	3	-	-	-	-	-	-
Oak	43	37	-	-	6	-	-	-
Crab apple	7	6	-	-	1	-	-	-
Maple	407	332	-	2	73	7	3	3
Sallow	16	13	-	1	2	2	2	-
Midland hawthorn	1821	1384	1	102	334	242	189	1
Common hawthorn	680	487	-	59	134	81	54	2
Ash	912	640	2	1	269	14	5	-
Moderate survival/loss								
Hazel	1822	959	-	12	851	290	73	1
Rose	15	8	-	-	7	2	-	-
Blackthorn	158	75	4	12	67	11	7	2
Elder	7	3	-	-	4	2	1	-
Birch	20	8	-	-	12	-	-	-
Spindle	10	3	-	2	5	-	-	-
Low survival/high loss								
Dogwood	155	37	-	2	116	11	3	1
Privet	237	54	113	3	67	9	-	5
Bramble	21	-	2	-	19	1	-	1
Aspen	6	0	0	0	6	-	-	-
Guelder rose	7	0	0	0	7	-	-	-
Honeysuckle	2	0	0	0	2	-	-	-
Total	**6349**	**4049**	**122**	**196**	**1982**	**672**	**337**	**16**

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 4: Fate and recruitment of stems alive >1.3m height between 1985-96.

The changes in living stem densities between 1985-96 (table 3) were a product of stem survival and recruitment (table 4). About two-thirds of the stems standing alive >1.3m height in 1985 survived through to 1996, and although most of the remainder died, a few remained alive either fallen or at the base only.

Survival patterns among the species were very variable. Amongst the major tree and understorey species survival of oak and maple was greater than ash, and hazel fared worst in the understorey. The mortality of midland hawthorn and common hawthorn stems was reduced by the survival of many fallen stems, an attribute also observed in spindle, blackthorn and sallow. Poor survival was common among the minor species, and no bramble, aspen, guelder rose or honeysuckle stems survived. However, although privet survival was poor, nearly half of the losses survived as reduced stems alive <1.3m height.

The decline in standing stems alive >1.3m was moderated by the recruitment of 672 stems, although half of these were either trunk shoots or forks that appeared to have been mostly overlooked in 1985. Midland hawthorn, common hawthorn and hazel were the only species to make substantial stem recruitment, but after removing those stems that were either recorded as trunk shoots or forks, then only hazel made substantial recruitment with 217 new stems recorded. Only 16 new individuals established themselves

Size-class fate of stems of major species alive >1.3m height 1985-96

For the major tree and understorey species, the size-class fate of stems standing alive >1.3m height in 1985 was examined (figures 4-9).

In 1985 the ash population (figure 4) appeared to comprise; (i) a large number of smaller stems (<10cm gbh), mainly advance seedling regeneration clustered in areas of relatively weak understorey growth, especially in the proximity of large dead birches that had presumably died following the 1976 drought; (ii) an extending cohort of stems, sized mainly between 20-100 cm gbh, that regenerated after the early 20th century fellings; (iii) a number of larger stems, probably including all those >100cm gbh, that represented retained stems from the early 20th century fellings. Ash mortality by 1996 was concentrated in the smallest size-class (<10cm gbh in 1985), with only 24% of stems in this class surviving alive >1.3m in 1996. Typically no trace could be found of these losses in the field in 1996 and very few remained as stems reduced to alive <1.3m height or as dead standing stems. Remaining mortality generally increased proportionally as size-class decreased and all stems >120cm gbh in 1985 survived. Mortality due to windblow included most of the largest stems that died. No stems in these size-classes were reduced to alive <1.3m, but many (63%) that died remained standing >1.3m height.

The 1985 maple population (figure 5) appeared to be mostly represented by an extending cohort that regenerated after the early 20th century fellings, together with a small number of stems that were retained at this time, including most of the larger stems (>100cm gbh). Mortality by 1996 was mostly of stems <80cm gbh in 1985, but three large trees died, two of which were toppled by windblow. In general mortality increased proportionally as stem size-class decreased and only about half (53%) of the stems that died remained standing in 1996. No stems were reduced to alive <1.3m.

The 1985 oak population (figure 6) appeared to have been primarily composed of stems that were retained during the early 20th century fellings. Most stems were large (>90cm gbh) and the smaller stems were mostly of coppice origin. Mortality between 1985-96 was greatest in the smaller size-classes and few stems that died had fallen over by 1996.

In 1985 the midland hawthorn population (figure 7) appeared to be comprised mainly of an extending cohort that regenerated after the early 20th century fellings, together with a few very large stems that could have been retained at this period. Mortality by 1996 was concentrated in the smaller size-classes (<20cm gbh in 1985) and the proportion of stems that died increased as stem size-class decreased. Of those that died 65% had fallen over by 1996, and of the stems that fell and remained alive most were relatively small (5-20cm gbh in 1985).

The 1985 size-class distribution of common hawthorn (figure 8) was similar to that of midland hawthorn, suggesting a similar historical origin, but the very large stems undoubtedly originated before and were retained during the early 20th century fellings. Mortality between 1985-96 was mainly of smaller stems (<20cm gbh in 1985) and many of these (72%) had fallen over by 1996. The proportional mortality generally increased as stem size-class decreased. The stems that fell and remained alive were relatively equally distributed amongst all size-classes up to 50cm gbh in 1985.

As with the hawthorn species, the 1985 size-class distribution of hazel (figure 9) suggested that the population was dominated by an expanding cohort that established after the early 20th century fellings. However the relatively large number of very small stems (<5cm gbh) probably included some recent regeneration. Although mortality between 1985-96 was mainly of smaller stems (<15cm gbh in 1985), unlike most other species proportional mortality was high in most size-classes and notably the larger size classes (>35cm gbh in 1985). Of those stems that died 60% had fallen by 1996 and the proportion falling was especially high for stems <10cm gbh in 1985.

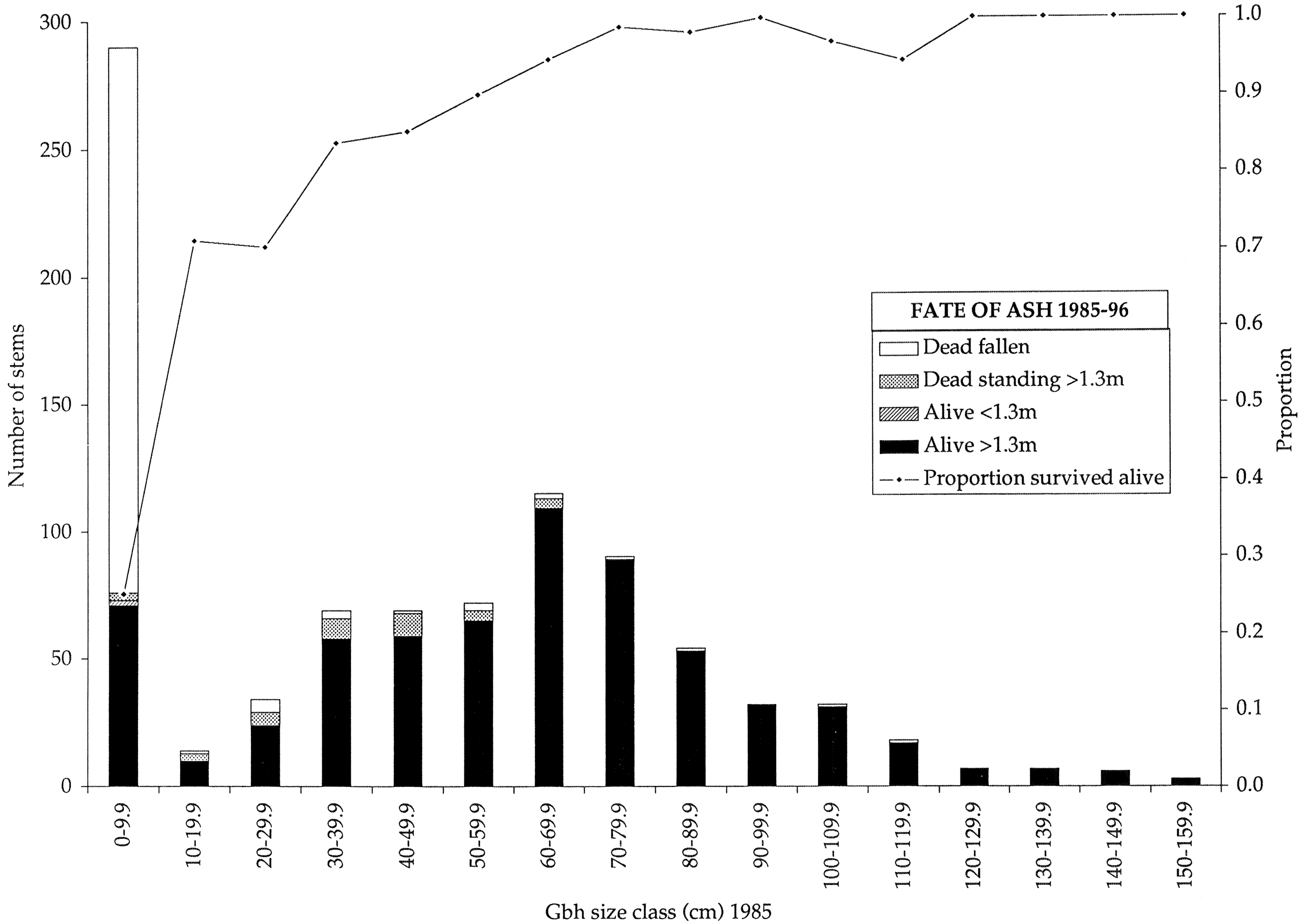


Figure 4: Size class fate and proportional survival of ash stems standing alive >1.3m height in 1985 by 1996.

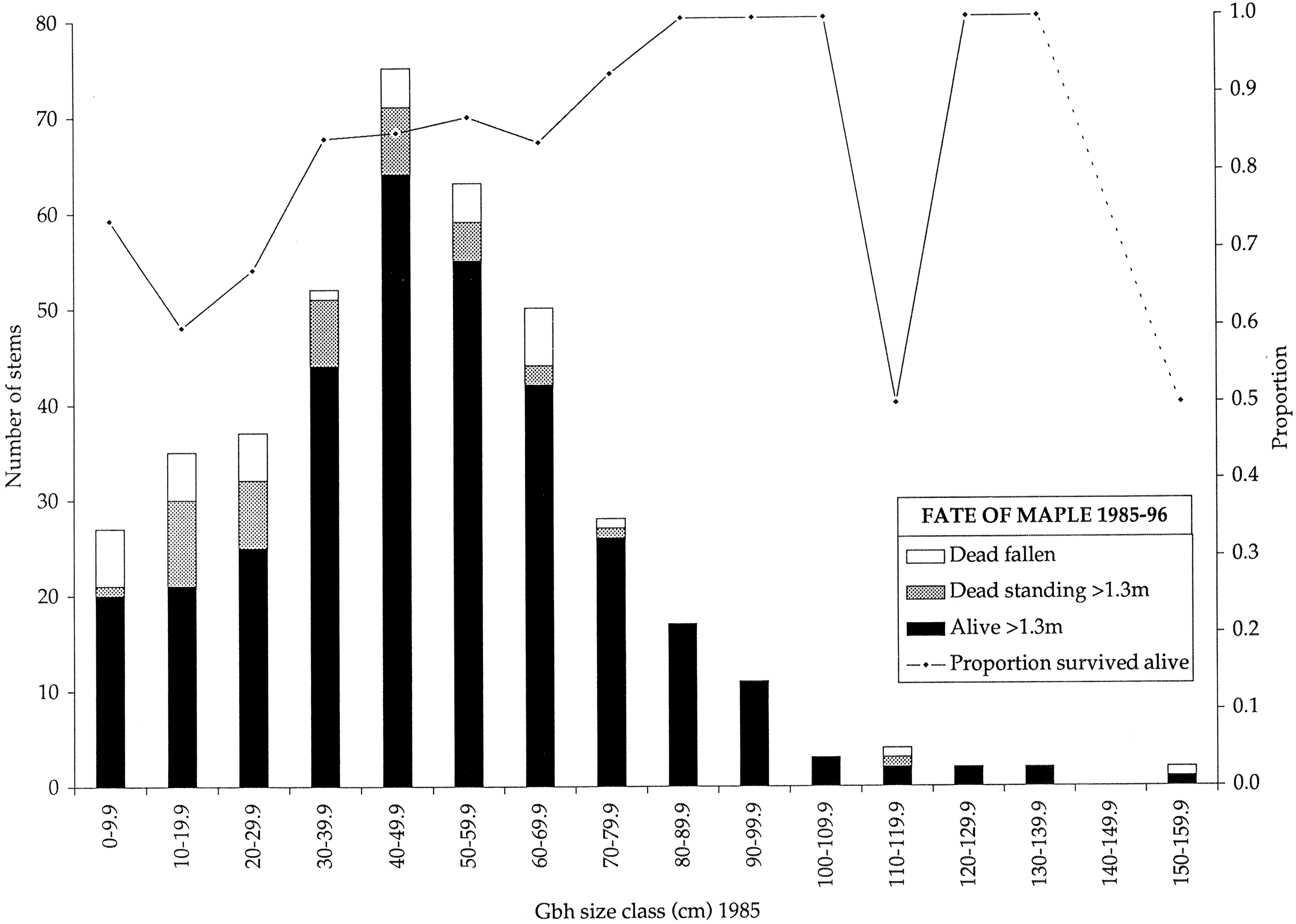


Figure 5: Size class fate and proportional survival of maple stems standing alive >1.3m height in 1985 by 1996.

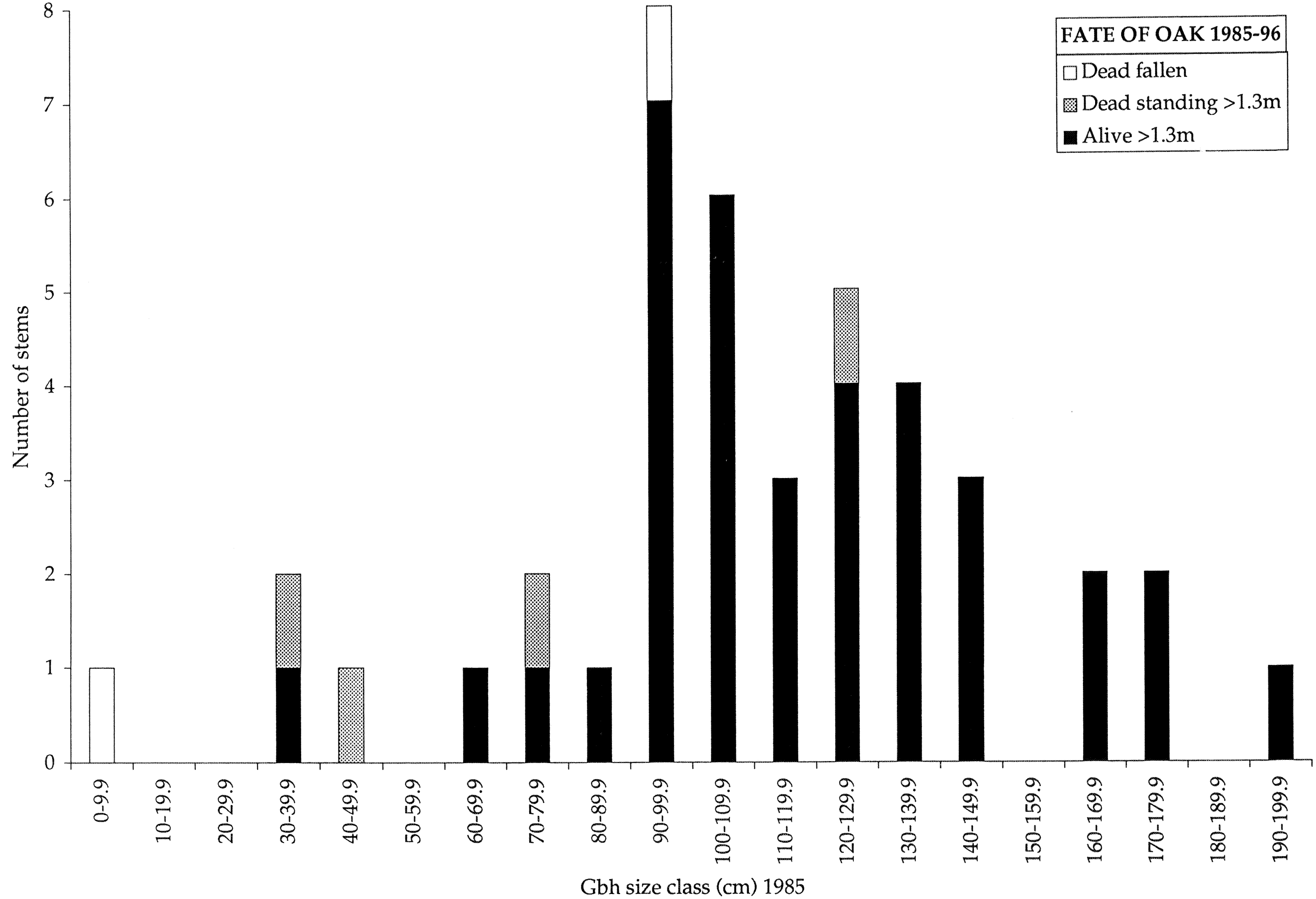


Figure 6: Size class fate of oak stems standing alive >1.3m height in 1985 by 1996.

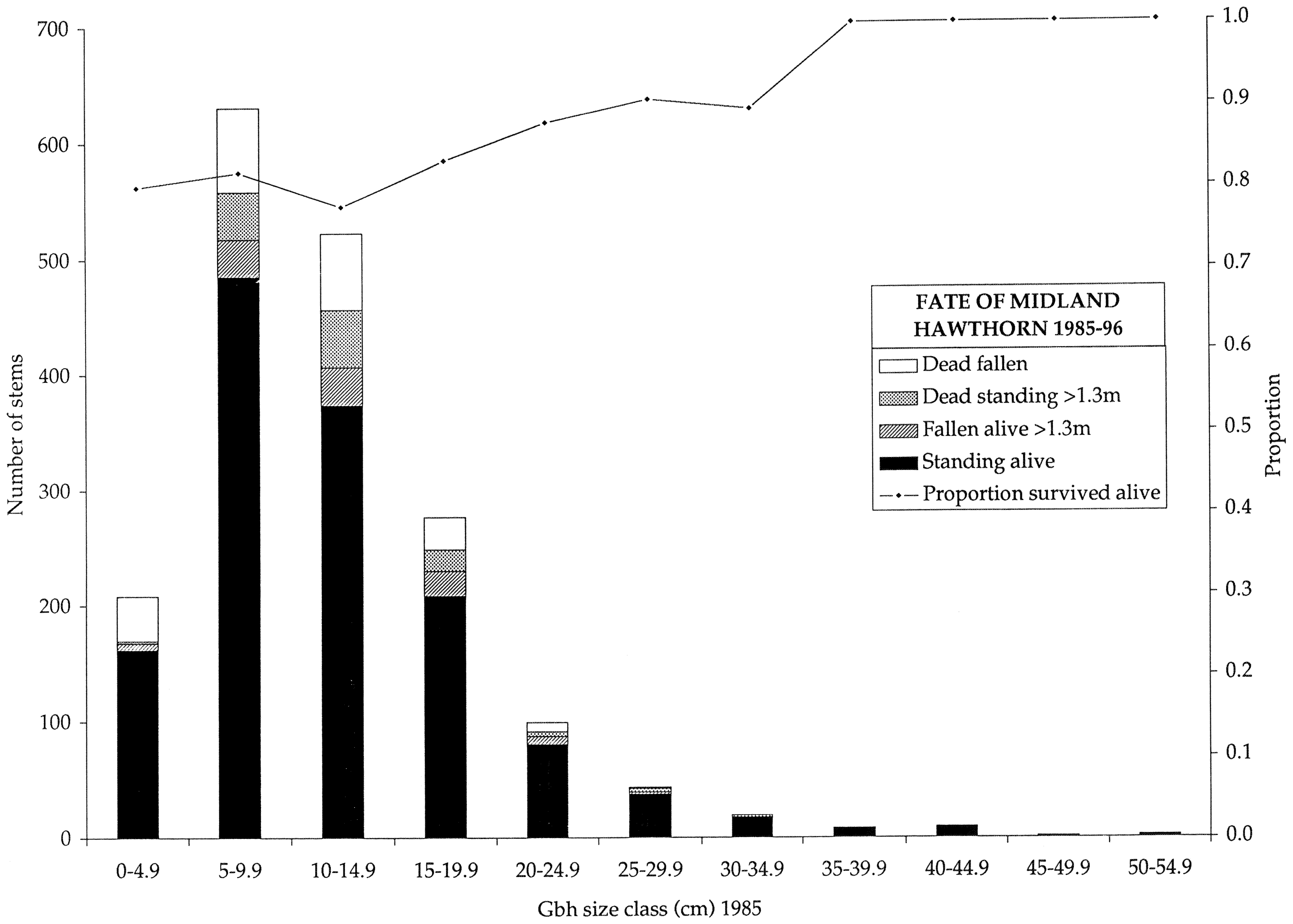


Figure 7: Size class fate and proportional survival of midland hawthorn stems standing alive >1.3m height in 1985 by 1996.

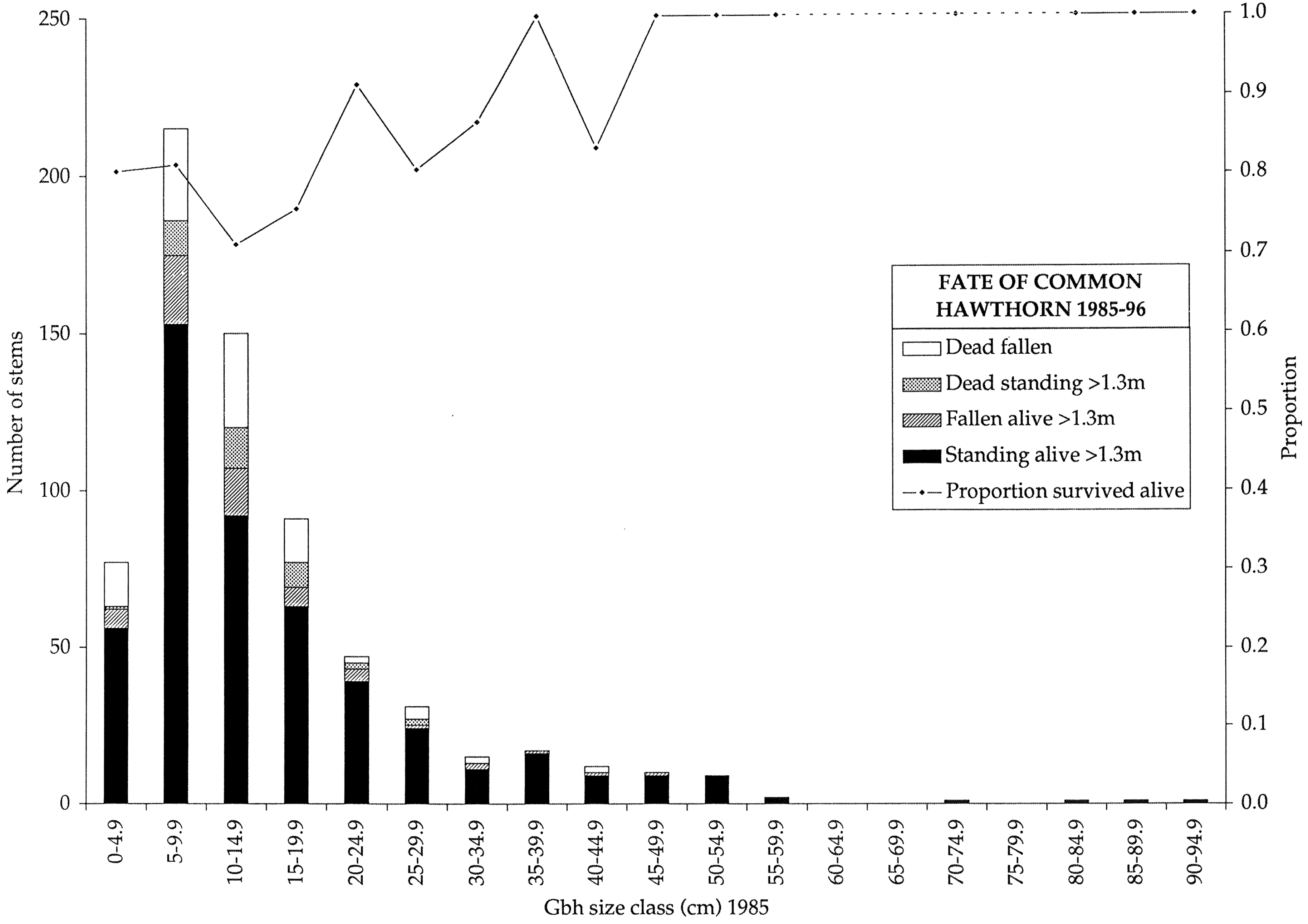


Figure 8: Size class fate and proportional survival of common hawthorn stems standing alive >1.3m height in 1985 by 1996.

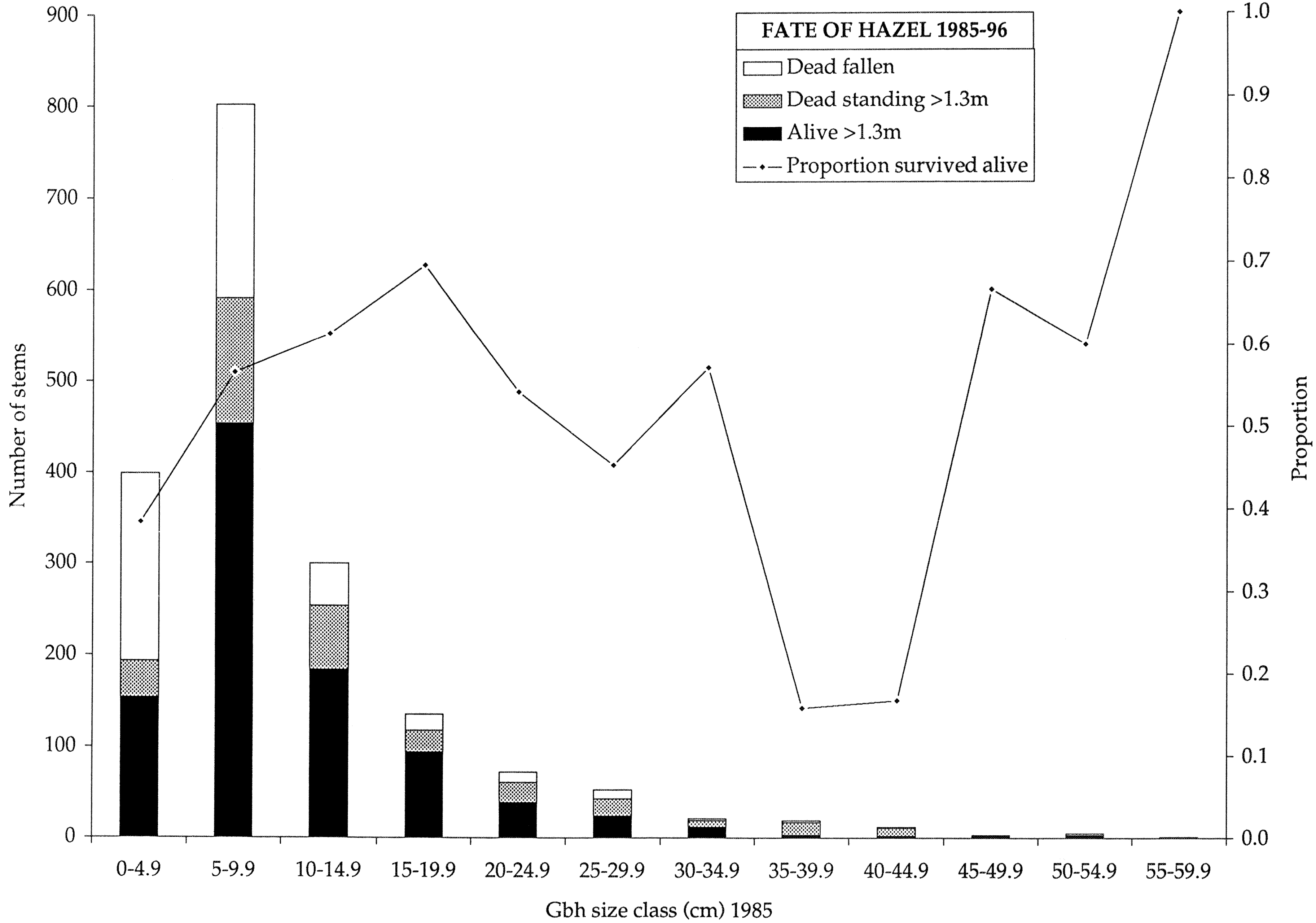


Figure 9: Size class fate and proportional survival of hazel stems standing alive >1.3m height in 1985 by 1996.

Fate and recruitment of stems alive <1.3m height 1985-96

	1985	Fate of 1985 stems by 1996			Recruitment 1985-96	
	Stems standing alive <1.3m	Standing alive <1.3m	Standing alive >1.3m	Died	Not present in 1985	Alive >1.3m in 1985
	n	n	n	n	n	n
Ash	369*	2	5	362	-	2
Blackthorn	131*	-	-	131	-	4
Bramble	46*	-	-	46	2	-
Privet	14*	5	-	9	6	109
Dogwood	10	-	-	10	-	-
Midland hawthorn	3	-	-	3	-	1
Oak	1	-	-	1	-	-
Total	**574**	**7**	**5**	**562**	**8**	**116**

(includes estimated number from seedling groups; calculated using all recorded stems alive <1.3m in 1985 and 1996)*

Table 5: Fate and recruitment of stems alive <1.3m height between 1985-96.

In 1985 nearly 600 stems were recorded as alive <1.3m height, represented mainly by advanced regeneration seedling ash and suckering or seedling blackthorn, together with a small number of low-growing dogwood, privet and bramble bushes. However by 1996 virtually all of these stems had died, with only privet surviving in any substantial number. A moderate amount of period recruitment occurred, but this was mainly of privet stems that been reduced from alive >1.3m in 1985. Only a few new privets established, which, given its suckering, sprawling, and bushy habitat, could easily have been overlooked in 1985.

6. GROWTH

Growth of stems of major tree species standing alive >1.3m height 1985-96

	Regression equation	n	F	p	r^2
Ash	y = 0.0110x - 0.0951	624	477.8	<<0.0001	0.434
Maple	y = 0.0022x + 0.1582	317	16.9	<0.0001	0.051
Oak	y = 0.0077x - 0.0674	40	7.4	0.01	0.162

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 6: Summary statistics for the regressions of stem gbh change rates (cm a^{-1}) on initial gbh size (cm) from 1985-96 for major tree species.

The growth between 1985-96 of ash, maple and oak was examined by determining the linear regression of stem gbh (cm) change rate per annum on initial size. For all species stem gbh change was significantly and positively related to initial size (table 6), inferring that larger stems grew faster than smaller. The relationship for ash was especially strong ($p<<0.0001$) and accounted for 43% of the total variation. The relationship for maple was also highly significant ($p<0.0001$), but accounted for little variation (5%), whilst the regression for oak was far less significant ($p = 0.01$).

The three regression equation slopes were compared using analysis of covariance (ANCOVAR) and were found to be significantly different ($F = 120.2$, $p<<0.0005$). Pairs of slopes were then compared using the Tukey test, and ash was found to be significantly greater than oak ($q = 24.9$, $p<<0.001$), and oak significantly greater than maple ($q = 17.08$, $p<<0.001$).

Stem canopy position; crown size	Number of stems	Mean rate	Standard deviation
Canopy; large	11	1.322	0.483
Canopy; medium	83	1.271	0.414
Canopy; small	198	0.846	0.291
Canopy; very small	149	0.457	0215
Sub-canopy; all	46	0.336	0.171
Understorey or ground; all	137	0.264	0.205

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 7: Mean and standard deviation gbh change rates between 1985-96 (cm a^{-1}) for ash stems in various canopy and crown size categories in 1996.

The influence of canopy position and crown size on stem growth was examined. Ash showed a relatively clear effect (figure 10; table 7); typically the largest and most rapidly growing stems had large or medium crowns in the uppermost canopy layer, whereas the slowest had smaller crowns in the understorey or ground layers.

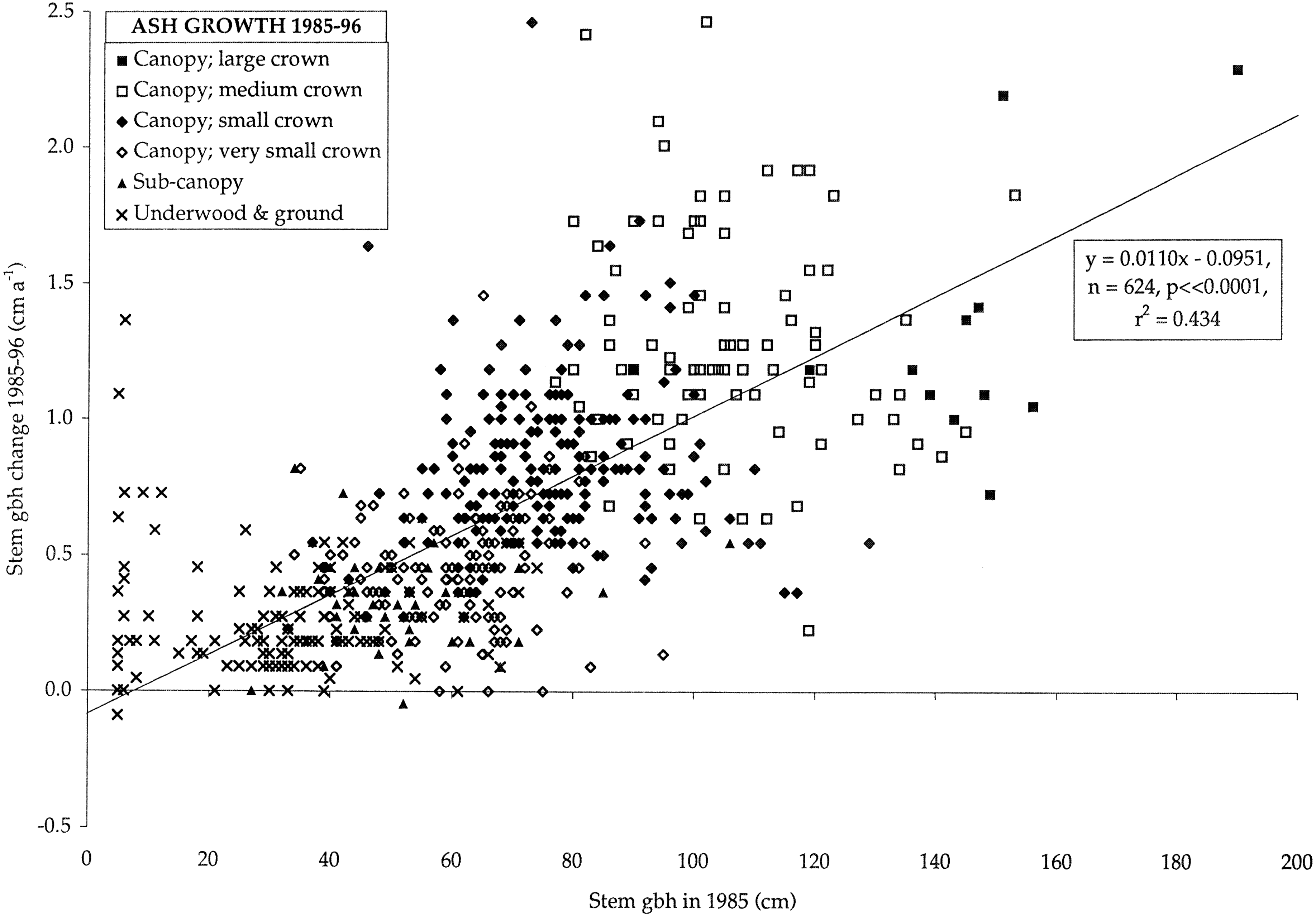


Fig 10: Relationship between gbh change and intital size for ash stems 1985-96. The linear regression line and equation, and the canopy position and crown size of stems in 1996 are shown.

Stem canopy position; crown size	Under-storey or ground; all	Sub-canopy; all	Canopy; very small	Canopy; small	Canopy; medium
Canopy; large	*<0.001*	*<0.001*	*<0.001*	*<0.001*	0.706
Canopy; medium	*<0.001*	*<0.001*	*<0.001*	*<0.001*	-
Canopy; small	*<0.001*	*<0.001*	*<0.001*	-	-
Canopy; very small	*<0.001*	*0.001*	-	-	-
Sub-canopy; all	*0.033*	-	-	-	-

(numbers are probability values for significance of difference between categories; those in italics are significant)

Table 8: Significance of ANOVA comparisons between mean gbh change rates from 1985-96 (cm a^{-1}) for ash stems in various canopy and crown size categories in 1996.

The mean growth of ash stems in the various canopy and crown size categories (table 7) were compared using ANOVA (table 8). The results generally confirmed the apparent pattern, although no significant difference existed between large and medium crowns in the canopy.

Stem canopy position; crown size	Number of stems	Mean rate	Standard deviation
Canopy; medium	6	0.830	0.228
Understorey; large	10	0.536	0.215
Sub-canopy; medium	6	0.349	0.214
Canopy; small/very small	56	0.343	0.214
Understorey; medium	96	0.299	0.199
Sub-canopy; small	36	0.285	0.216
Sub-canopy; very small	20	0.186	0.210
Understorey; small/very small	79	0.170	0.157
Ground; all	9	0.152	0.176

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 9: Mean and standard deviation gbh change rates between 1985-96 (cm a^{-1}) for maple stems in various canopy and crown size categories in 1996.

The effect of canopy position and crown size on maple stem growth was less definitive (figure 11; table 9), but in general faster growing stems appeared to have larger crowns and the slowest growing stems were moreover small and in the lowest canopy layers. ANOVA testing confirmed the significance of many of these mean growth rate differences, although several categories were not significantly different (table 10).

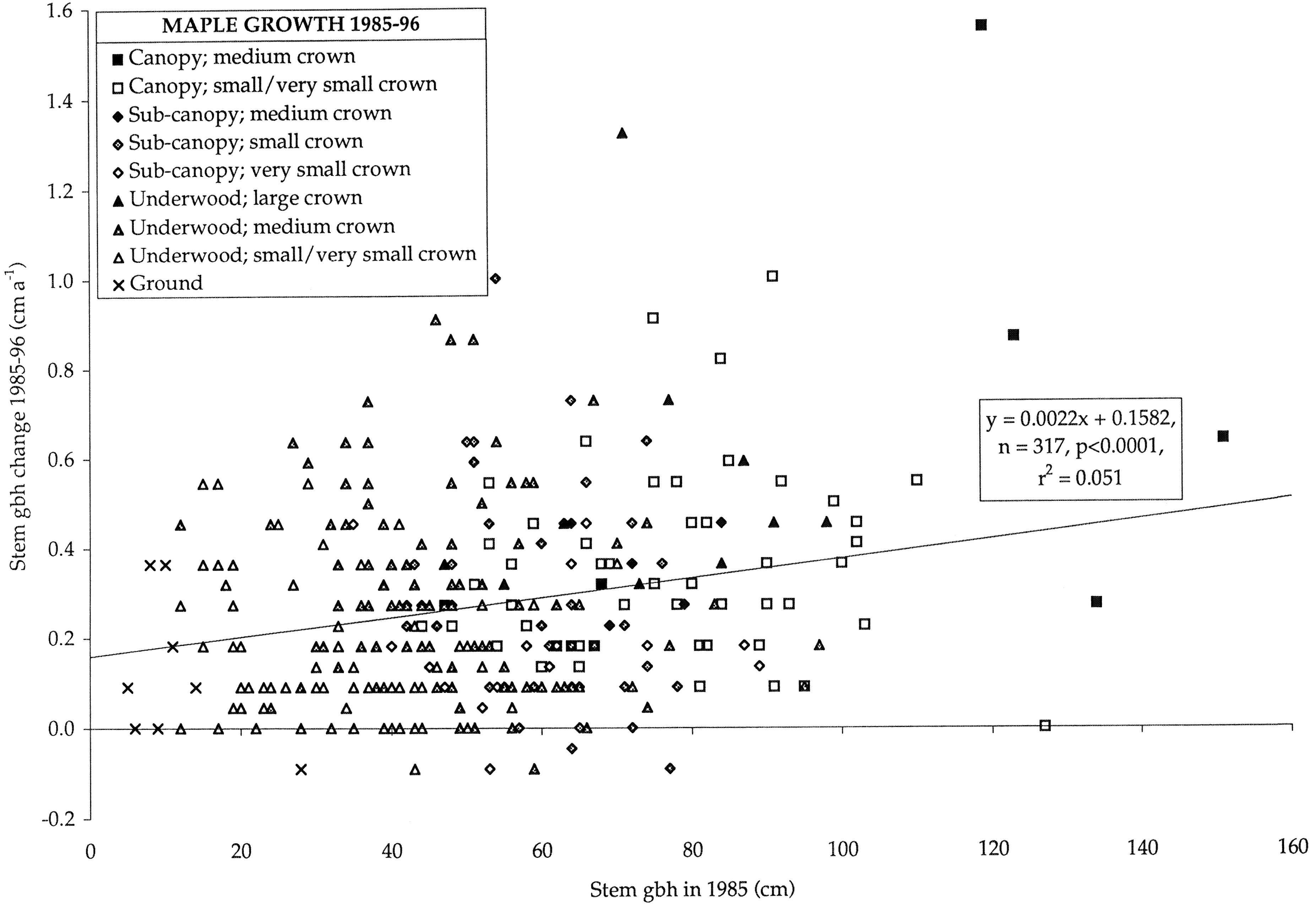


Fig 11: Relationship between gbh change and intital size for maple stems 1985-96. The linear regression line and equation, and the canopy position and crown size of stems in 1996 are shown.

Canopy position		Ground	Under-storey	Sub-canopy	Sub-canopy	Under-storey	Canopy	Sub-canopy	Under-storey
	Crown size	All	Small/ very small	Very small	Small	Medium	Small/ very small	Medium	Large
Canopy	Medium	*0.005*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*0.058*	0.211
Understorey	Large	*0.004*	*<0.001*	*0.001*	*0.010*	*0.002*	*0.012*	0.166	-
Sub-canopy	Medium	*0.027*	*0.007*	*0.011*	0.549	0.577	0.951	-	-
Canopy	Small/very small	*0.009*	*<0.001*	*0.002*	0.223	0.211	-	-	-
Understorey	Medium	*0.047*	*<0.001*	*0.025*	0.752	-	-	-	-
Sub-canopy	Small	0.140	*0.003*	0.107	-	-	-	-	-
Sub-canopy	Very small	0.560	0.662	-	-	-	-	-	-
Understorey	Small/very small	0.743	-	-	-	-	-	-	-

(numbers are probability values for significance of difference between categories; those in italics are significant)

Table 10: Significance of ANOVA comparisons between mean gbh change rates from 1985-96 (cm a^{-1}) for maple stems in various canopy and crown size categories in 1996.

Stem canopy position; crown size	Number of stems	Mean rate	Standard deviation
Canopy; large	6	1.727	0.765
Canopy; medium	16	1.057	0.458
Canopy; small/very small	13	0.528	0.343
Sub-canopy/understorey; all	7	0.318	0.198

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 11: Mean and standard deviation gbh change rates between 1985-96 (cm a^{-1}) for oak stems in various canopy and crown size categories in 1996.

A general effect of canopy position and crown size on oak stem growth was evident (figure 12; table 11), with large and medium sized canopy stems typically growing more rapidly than smaller-sized canopy stems and those stems in the lowest canopy layers. ANOVA testing confirmed that the apparent mean growth rate differences were significant (table 12).

Stem canopy position; crown size	Sub-canopy/ under-wood; all	Canopy; small/very small	Canopy; medium
Canopy; large	*0.001*	*<0.001*	*0.034*
Canopy; medium	*<0.001*	*0.002*	-
Canopy; small/very small	0.156	-	-

(numbers are probability values for significance of difference between categories; those in italics are significant)

Table 12: Significance of ANOVA comparisons between mean gbh change rates from 1985-96 (cm a^{-1}) for oak stems in various canopy and crown size categories in 1996.

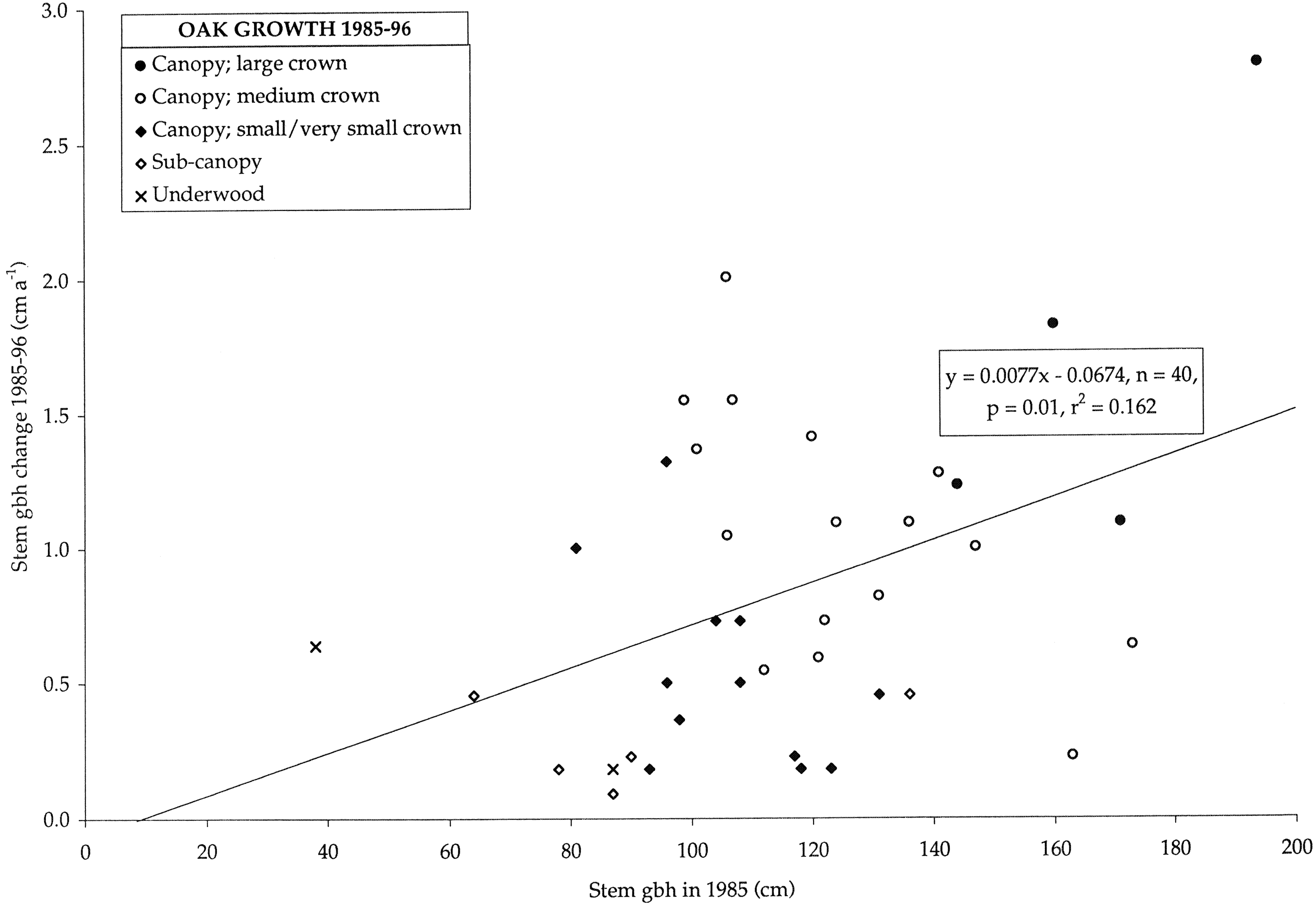


Fig 12: Relationship between gbh change and intital size for oak stems 1985-96. The linear regression line and equation, and the canopy position and crown size of stems in 1996 are shown.

Growth of stems of major understorey species standing alive >1.3m 1985-96

	Regression equation	n	F	p	mean	St. dev.
Hazel	y = -0.0018x + 0.3739	750	1.6	0.21	0.354	0.278
Common hawthorn	y = 0.0008x + 0.2403	316	0.6	0.45	0.256	0.265
Midland hawthorn	y = 0.0004x + 0.1980	915	0.2	0.68	0.204	0.215

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 13: Summary statistics for regression of stem gbh change rate (cm a^{-1}) on initial gbh size (cm) and mean rate (cm a^{-1}) from 1985-96 for major understorey species.

The growth from 1985-96 of midland hawthorn, common hawthorn and hazel stems was examined by determining the linear regression of stem gbh (cm) change per annum on initial size. No species showed a significant relationship, and therefore the mean stem gbh change rates (cm per annum) were calculated (table 13). Hazel had the greatest mean, followed by common hawthorn and then midland hawthorn. The means were compared using analysis of variance (ANOVA), and the hazel growth rate was found to be significantly greater than common hawthorn ($F = 28.3$, $p \ll 0.0001$), and common hawthorn significantly greater than midland hawthorn ($F = 12.3$, $p = 0.0005$).

Stem canopy position; crown size	Number of stems	Mean rate	Standard deviation
Understorey; medium	32	0.411	0.281
Understorey; small	223	0.280	0.244
Ground; large/medium	48	0.277	0.247
Understorey; very small	337	0.183	0.182
Ground; small	180	0.149	0.180
Ground; very small	95	0.094	0.150

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 14: Mean and standard deviation gbh change rates between 1985-96 (cm a^{-1}) for midland hawthorn stems in various canopy and crown size categories in 1996.

The influence of canopy position and crown size on stem growth was examined by determining the mean growth rates for stems in different positions and of different crown sizes in 1996 (table 14). For midland hawthorn the fastest mean growth rate was for medium sized understorey stems, with similar sized stems in the ground layer having a much lower mean rate. Smaller sized understorey stems also had a lower mean rate, and the smaller ground layer stems had still slower rates. ANOVA testing confirmed that these apparent mean growth rate differences were significant (table 15).

Common hawthorn and hazel showed very similar patterns to midland hawthorn (tables 16 and 17), and ANOVA inferred that many of the apparent differences between the mean growth rates were significant (table 18 and 19).

Canopy position		Ground	Ground	Under-storey	Ground	Under-wood
	Crown size	Very small	Small	Very small	Large/ medium	Small
Understorey	Medium	*<0.001*	*<0.001*	*<0.001*	*0.027*	*0.006*
Understorey	Small	*<0.001*	*<0.001*	*<0.001*	0.923	-
Ground	Large/medium	*<0.001*	*<0.001*	*0.002*	-	-
Understorey	Very small	*<0.001*	*0.041*	-	-	-
Ground	Small	*0.012*	-	-	-	-

(numbers are probability values for significance of difference between categories; those in italics are significant)

Table 15: Significance of ANOVA comparisons between mean gbh change rates from 1985-96 (cm a^{-1}) for midland hawthorn stems in various canopy and crown size categories in 1996.

Stem canopy position; crown size	Number of stems	Mean rate	Standard deviation
Understorey; large	7	0.558	0.523
Understorey; medium	50	0.394	0.248
Ground; large/medium	15	0.315	0.344
Understorey; small	114	0.315	0.274
Understorey; very small	80	0.179	0.195
Ground; very small	19	0.091	0.163
Ground; small	32	0.071	0.114

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 16: Mean and standard deviation gbh change rates between 1985-96 (cm a^{-1}) for common hawthorn stems in various canopy and crown size categories in 1996.

Canopy position		Ground	Ground	Under-storey	Under-storey	Ground	Under-storey
	Crown size	Small	Very small	Very small	Small	Large/ medium	Medium
Understorey	Large	*<0.001*	*0.002*	*<0.001*	*0.034*	0.205	0.166
Understorey	Medium	*<0.001*	*<0.001*	*<0.001*	*0.084*	0.332	-
Ground	Large/medium	*<0.001*	*0.017*	*0.032*	0.998	-	-
Understorey	Small	*<0.001*	*<0.001*	*<0.001*	-	-	-
Understorey	Very small	*0.004*	*0.073*	-	-	-	-
Ground	Very small	0.611	-	-	-	-	-

(numbers are probability values for significance of difference between categories; those in italics are significant)

Table 17: Significance of ANOVA comparisons between mean gbh change rates from 1985-96 (cm a^{-1}) for common hawthorn stems in various canopy and crown size categories in 1996.

Stem canopy position; crown size	Number of stems	Mean rate	Standard deviation
Understorey; medium	37	0.677	0.375
Understorey; small	309	0.458	0.284
Ground; medium	7	0.331	0.196
Understorey; very small	314	0.266	0.207
Ground; small	50	0.165	0.128
Ground; very small	33	0.149	0.216

(calculated using all recorded stems standing alive >1.3m in 1985 and 1996)

Table 18: Mean and standard deviation gbh change rates between 1985-96 (cm a^{-1}) for hazel stems in various canopy and crown size categories in 1996.

Canopy position	Crown size	Ground Very small	Ground Small	Understorey Very small	Ground Medium	Understorey Small
Understorey	Medium	*<0.001*	*<0.001*	*<0.001*	*0.022*	*<0.001*
Understorey	Small	*<0.001*	*<0.001*	*<0.001*	0.210	-
Ground	Medium	*0.046*	*0.004*	0.454	-	-
Understorey	Very small	*0.001*	*<0.001*	-	-	-
Ground	Small	0.676	-	-	-	-

(numbers are probability values for significance of difference between categories; those in italics are significant)

Table 19: Significance of ANOVA comparisons between mean gbh change rates from 1985-96 (cm a^{-1}) for hazel stems in various canopy and crown size categories in 1996.

7. STRATIFICATION

Crown position, size and dieback of major species in 1996

The status of all stems alive >1.3m height in 1996 was recorded by categorising stem crown position, crown size, and the extent of visible dieback.

	Canopy	Sub-canopy	Understorey	Ground
Ash	412	44	163	42
Maple	60	59	191	32
Oak	31	4	2	-
Midland hawthorn	-	-	968	876
Hazel	-	-	962	307
Common hawthorn	-	-	397	262
Others	7	4	129	154
Total	510	111	2812	1673

(calculated using all recorded stems alive >1.3m)

Table 20: Canopy positions of stems alive >1.3m height for major species in 1996.

Ash was the dominant species in the canopy layer (81% of all canopy stems) and a major component of the sub-canopy layer (40% of all sub-canopy stems) (table 20). Although quite numerous in the lowest layers, especially the understorey (25% of all ash stems), it accounted for <5% of all stems in these layers. Ash stems in the canopy layer were represented largely by 50-180cm gbh stems with relatively small crowns (figure 13). Stem gbh range decreased progressively through the lower crown layers, and in all layers increasing crown size was positively correlated with stem gbh (i.e. the largest stems tended to have the largest crowns), whilst crown dieback was typically negatively correlated with crown size (i.e. smaller crowns had more dieback) (figure 14). The large number of small gbh (<10cm gbh) and very small crowned stems in the understorey layer were mainly survivors from the rapidly developing seedling cohort that had developed in abundance in 1985 (table 5).

Maple was a minor component of the canopy layer (12% of all canopy stems), but accounted for about half of the stems in the sub-canopy layer (table 20). It was particularly numerous in the understorey (56% of all maple stems), but in this layer and the ground layer it accounted for a relatively small percentage of the total stem population. Although the very largest gbh maple stems were in the canopy layer, many were middle-sized stems with small or very small crowns (figure 15). Many of the stems in the understorey layer had medium-sized crowns and some of the largest gbh stems had particularly large crowns, but severe or very severe crown dieback was common (figure 16). Progressively down through the crown layers stem gbh range decreased, and in all layers crown size generally increased as stem gbh increased, whilst the amount of crown dieback generally increased as crown size decreased.

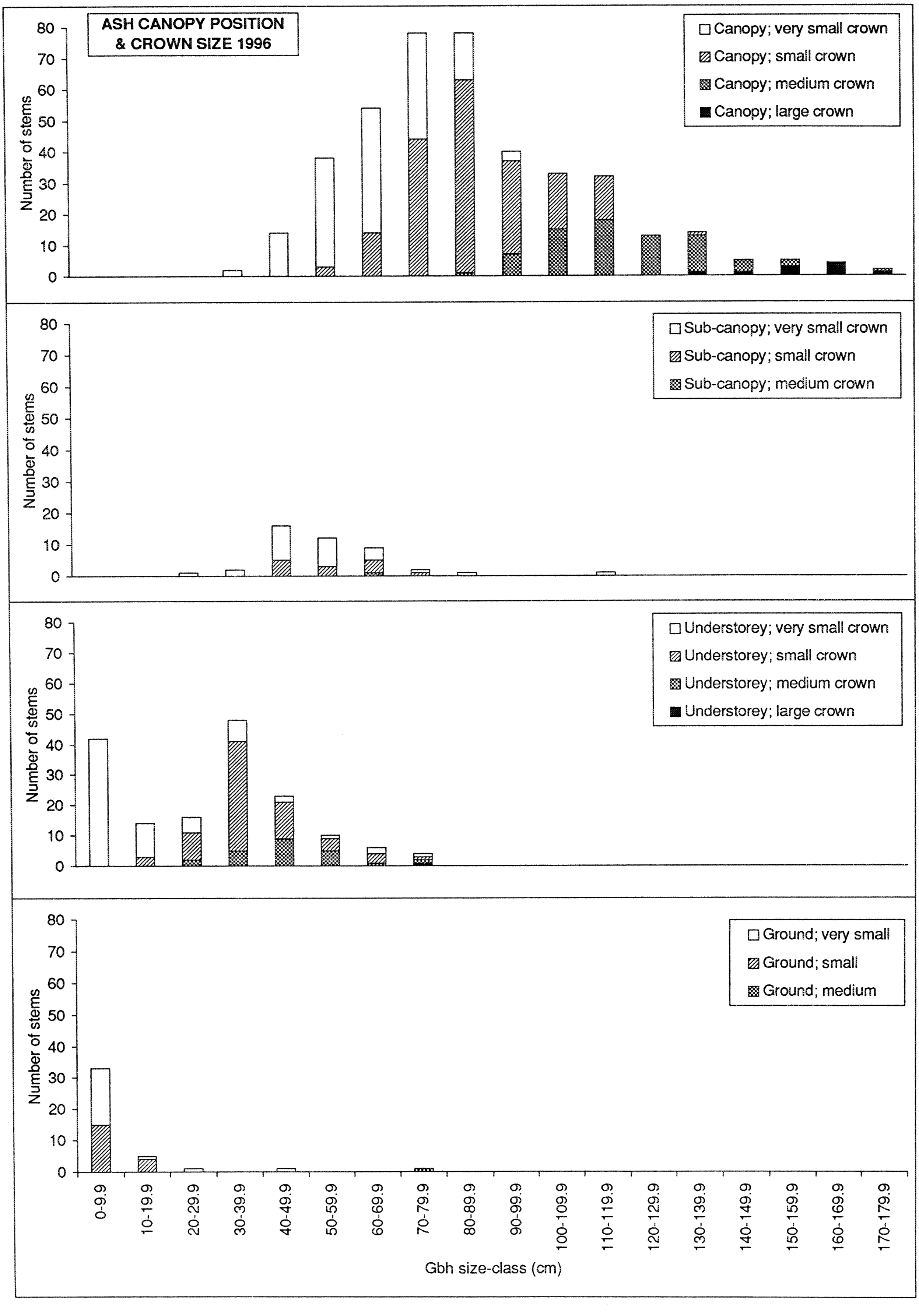


Figure 13: Canopy position and crown size of ash in relation to gbh in 1996.

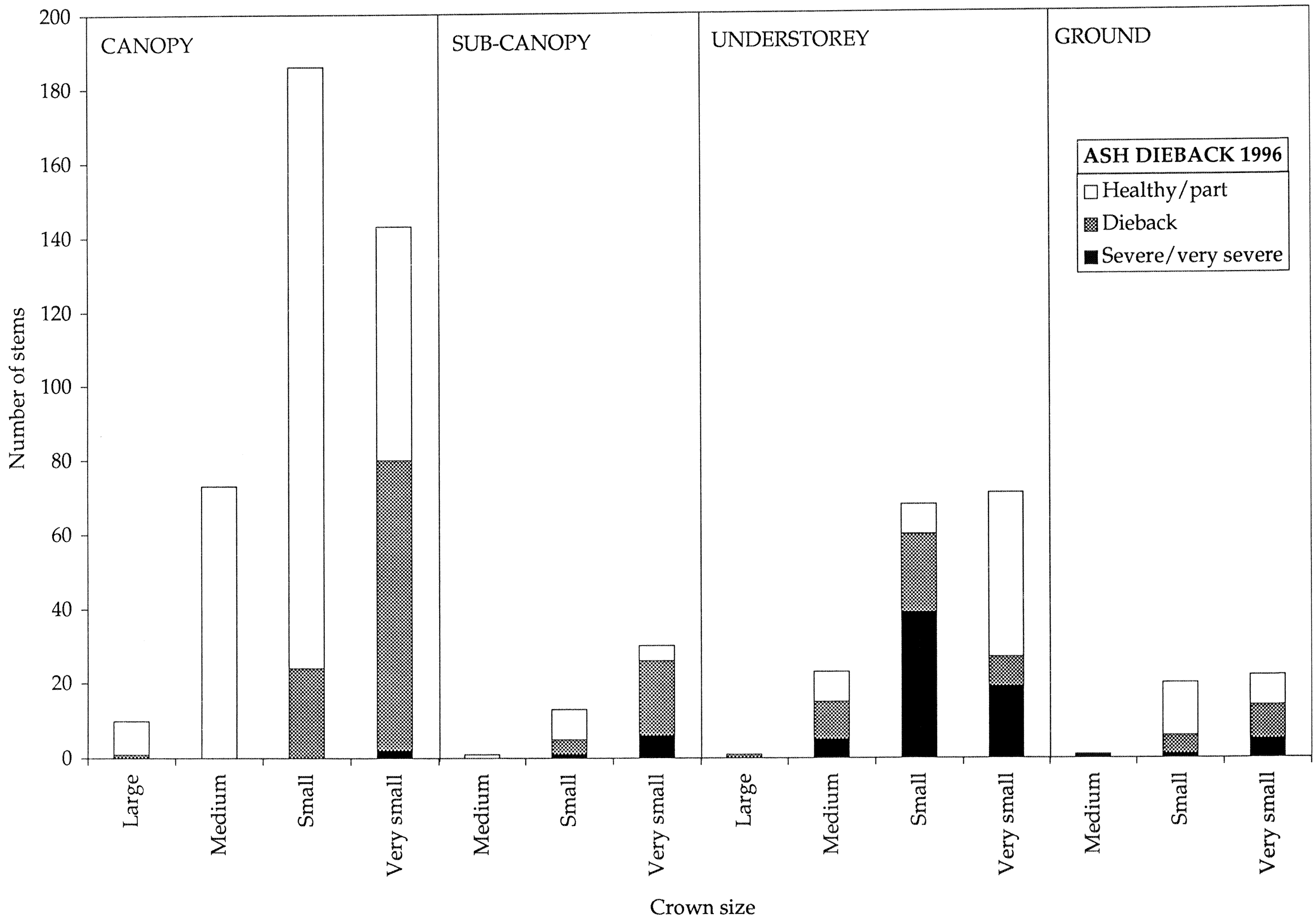


Figure 14: Extent of crown dieback in ash shown in relation to canopy position and crown size in 1996.

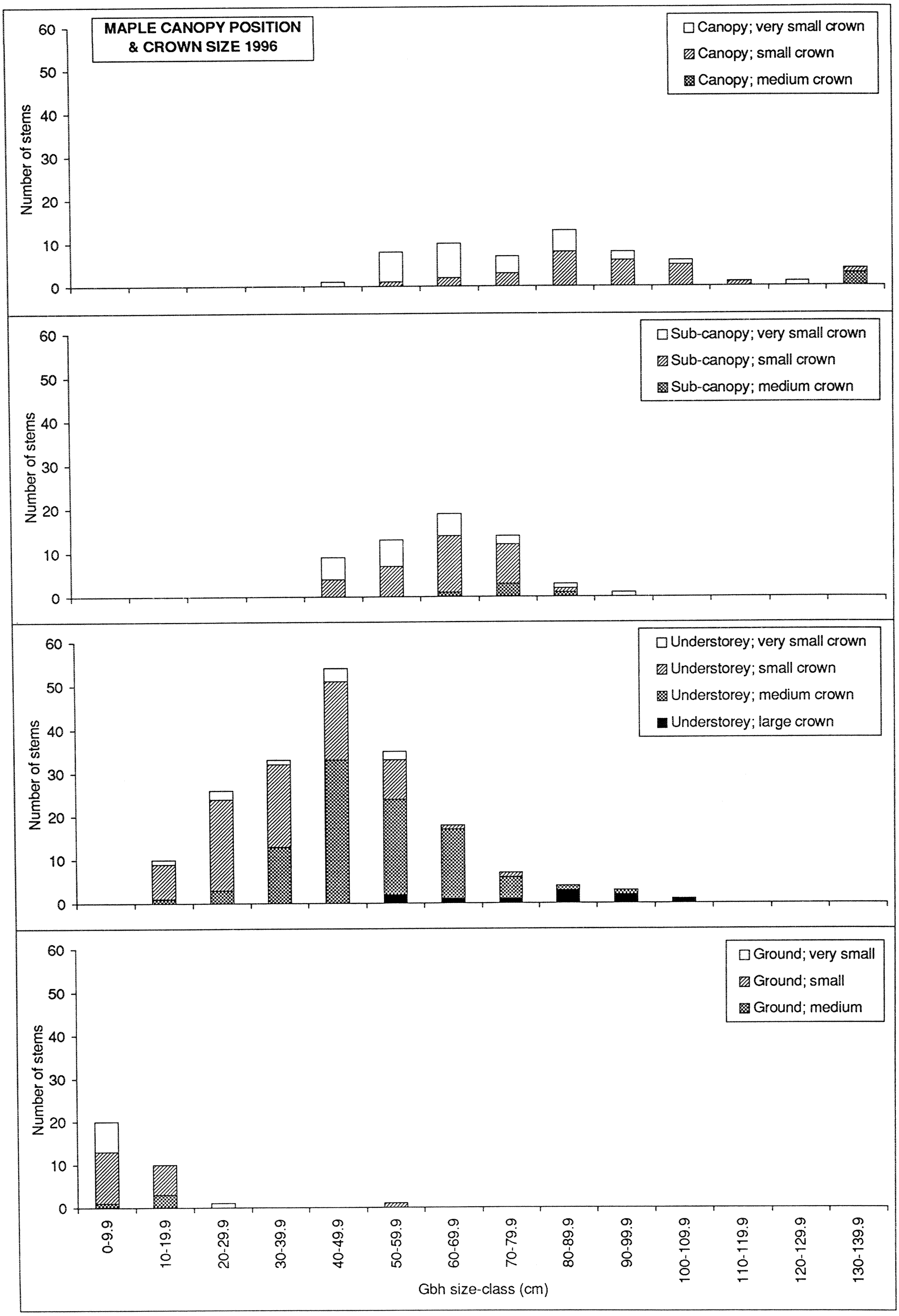


Figure 15: Canopy position and crown size of maple in relation to gbh in 1996.

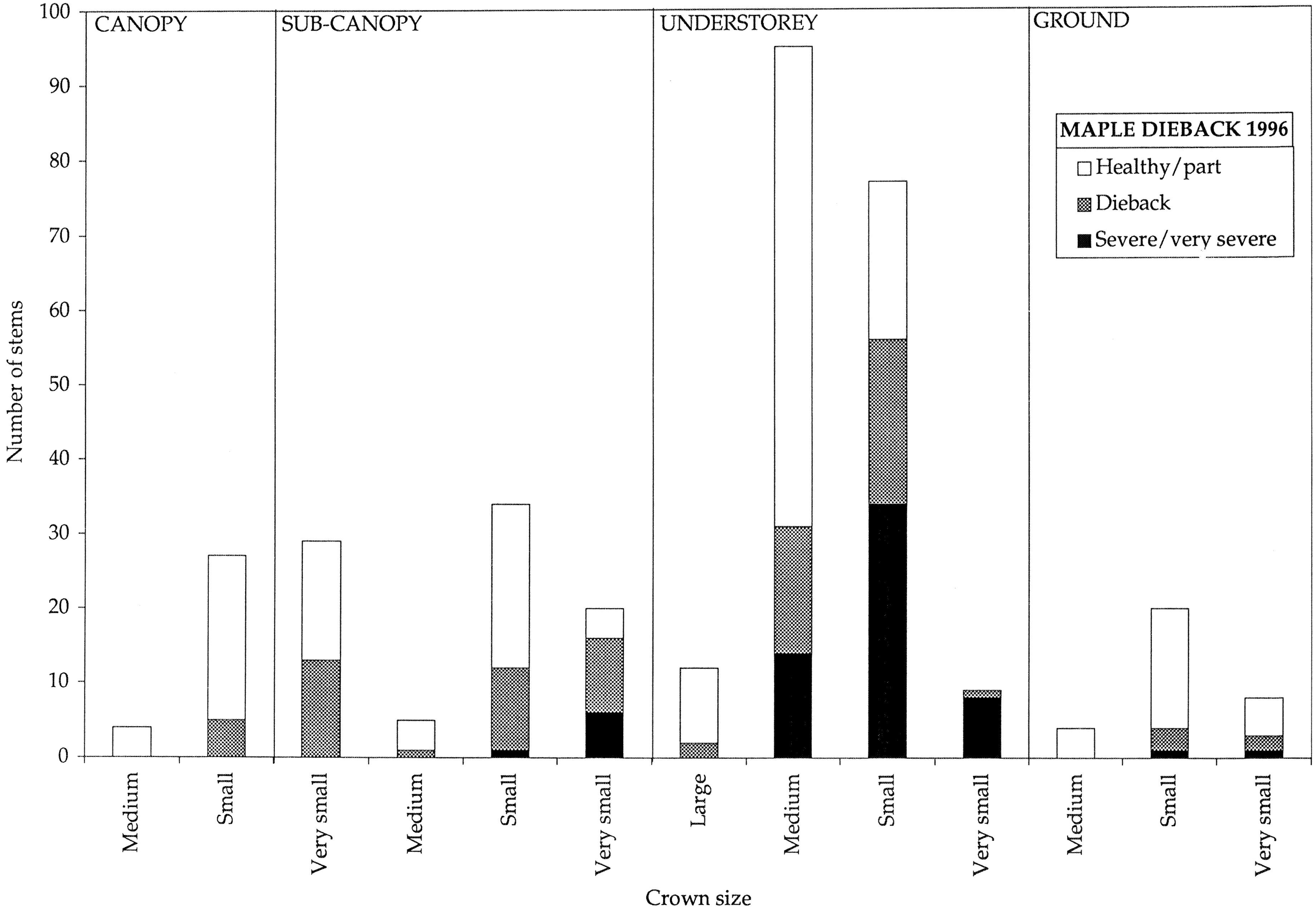


Figure 16: Extent of crown dieback in maple shown in relation to canopy position and crown size in 1996.

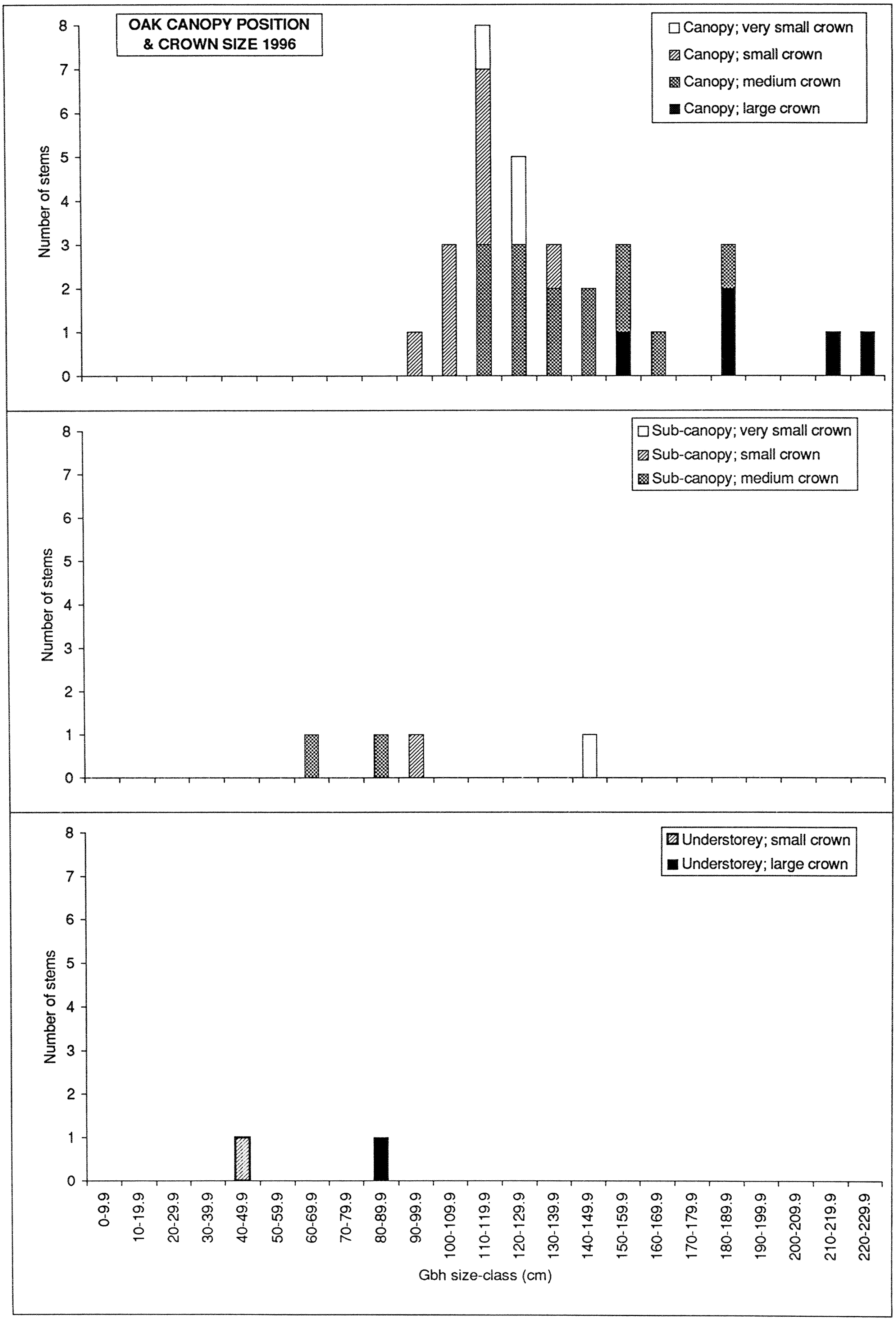


Figure 17: Canopy position and crown size of oak in relation to gbh in 1996.

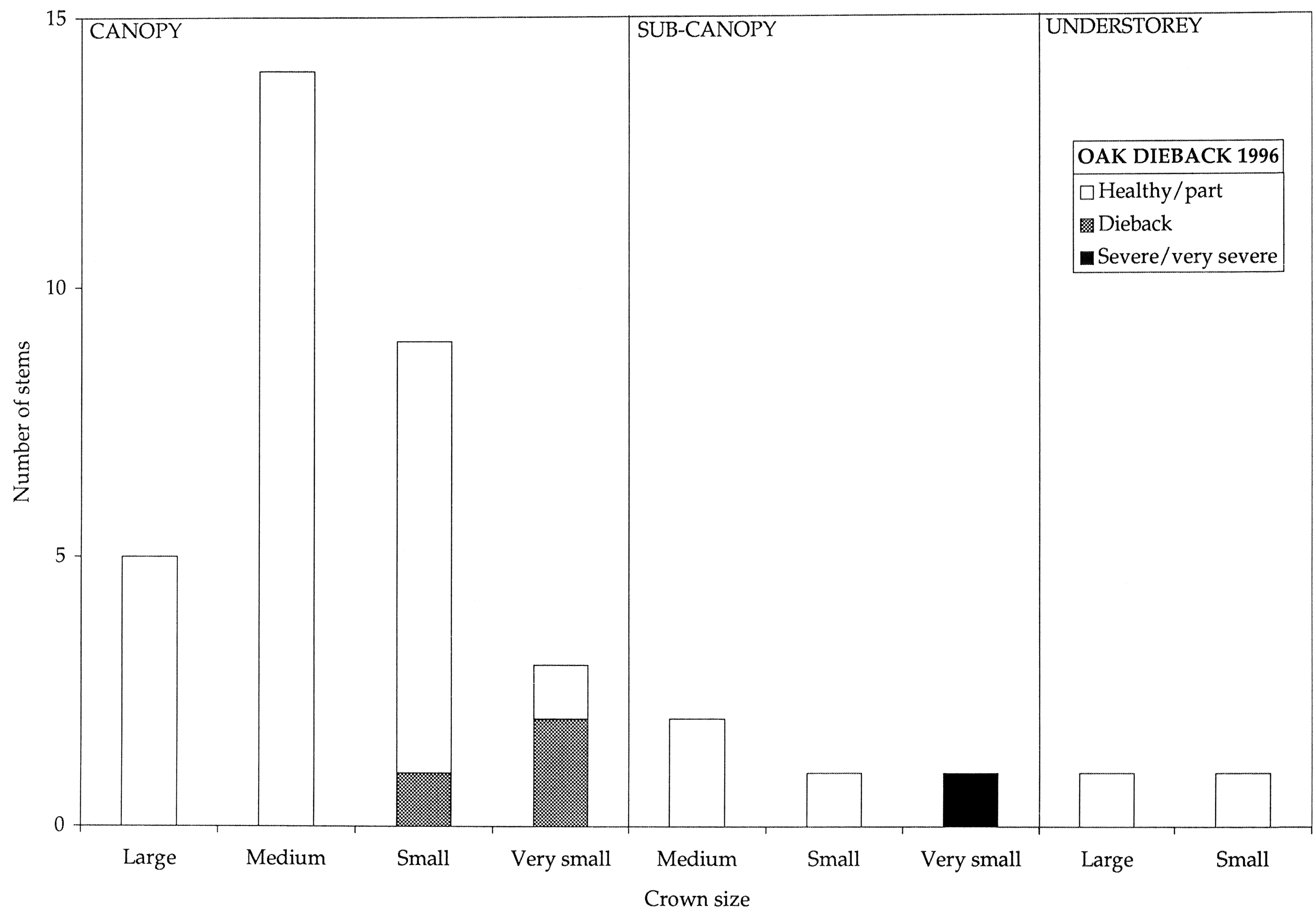


Figure 18: Extent of crown dieback in oak shown in relation to canopy position and crown size in 1996.

Oak stems were most abundant in the canopy layer (84% of all oak stems), but accounted for only a small percentage of all stems present (6% of all canopy stems) (table 20). The canopy layer stems were virtually all >90cm gbh (figure 17) and many had medium or large crowns with little dieback present (figure 18). Smaller stems were in the sub-canopy or understorey layers, where again dieback was relatively limited.

Midland hawthorn was co-dominant in the understorey (34% of all understorey stems), but was the most abundant species in the ground layer (52% of all ground stems) with nearly half of its stems recorded here (table 20). In the understorey all 0-60cm gbh size classes were represented (figure 19), with the smaller gbh stems having smaller crowns and more dieback (figure 21). The gbh range of stems in the ground layer was restricted to <35cm gbh, with 5-10cm gbh, small or very small crowned stems with moderate-large amounts of dieback especially abundant. A portion (21%) were stems that had fallen but remained alive, but most were splayed stems on complex multi-stemmed stools.

Common hawthorn was especially abundant in the ground layer (40% of all common hawthorn stems), and accounted for about 15% of all stems in the understorey and ground layers (table 20). As with other species, in both layers as crown size increased gbh increased, while the severity of dieback increased as crown size decreased (i.e. the smallest gbh stems had smaller crowns with more dieback and many of these were in the ground later) (figures 21-22). Like midland hawthorn, almost 25% of ground layer stems had fallen and remained alive, but most were splayed stems on complex multi-stemmed stools.

Hazel was the other co-dominant understorey species (34% of all understorey stems) and was moderately abundant in the ground layer (18% of all ground stems) (table 20). In both canopy layers crown size was positively correlated with stem gbh and crown dieback with decreasing crown size (figures 23-24). Understorey stems ranged from 0-60cm gbh, but most were 5-20cm gbh with small or very small crowns and limited dieback. In the ground layer gbh range was much reduced, most stems had small or very small crowns, crown dieback was especially common, and most were erect rather than fallen or splayed stems on multi-stemmed stools.

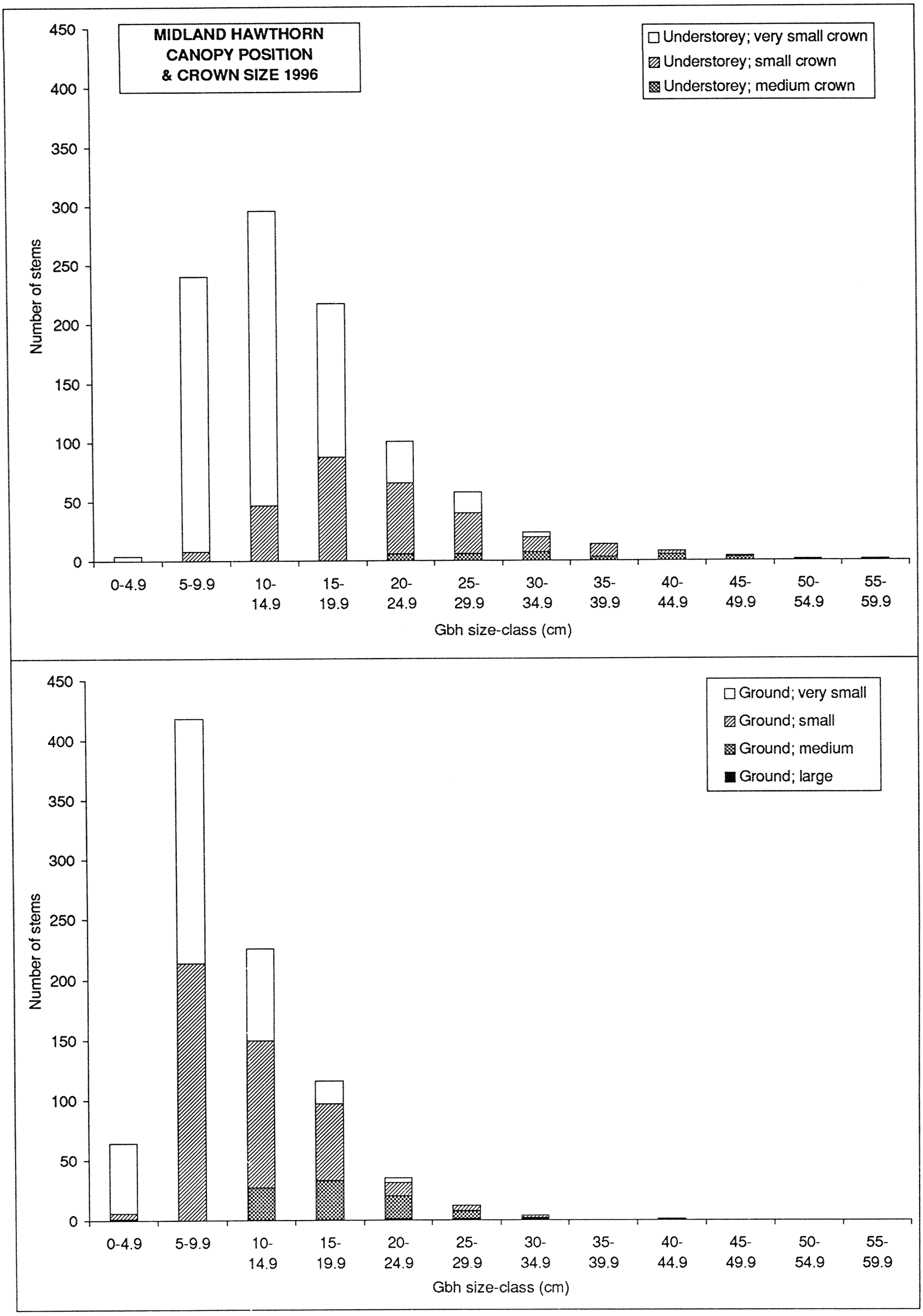


Figure 19: Canopy position and crown size of midland hawthorn in relation to gbh in 1996.

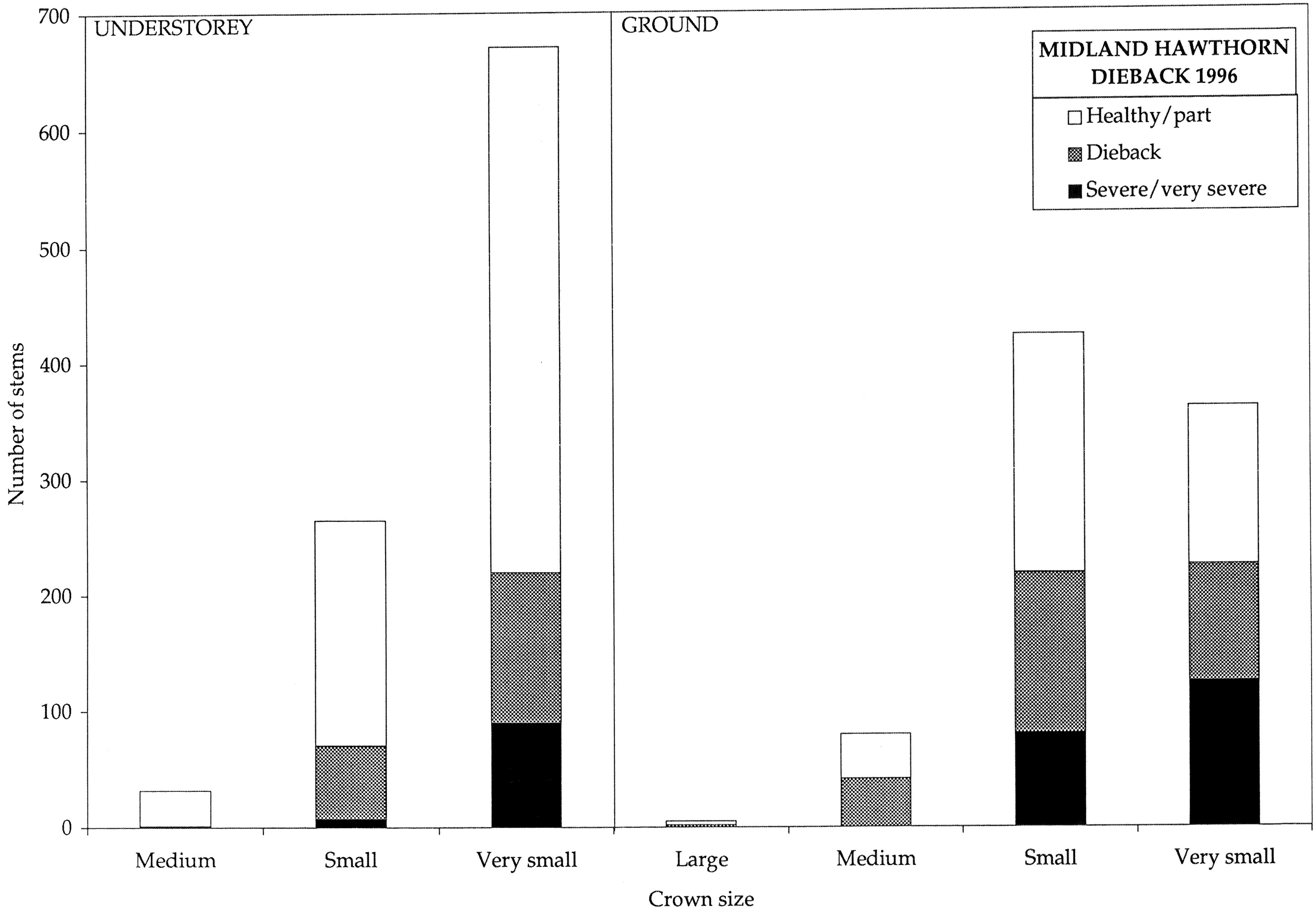


Figure 20: Extent of crown dieback in midland hawthorn shown in relation to canopy position and crown size in 1996.

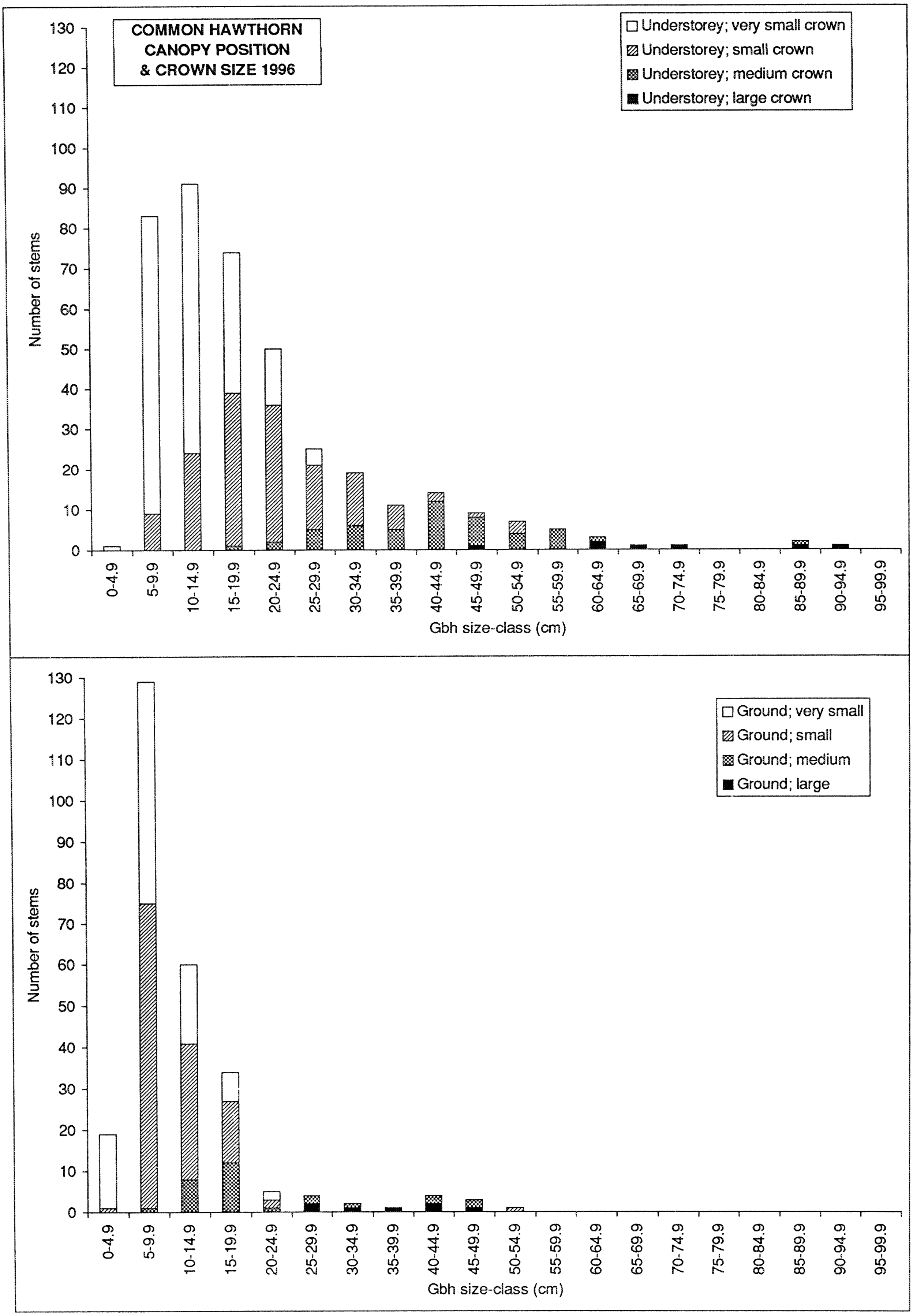


Figure 21: Canopy position and crown size of common hawthorn in relation to gbh in 1996.

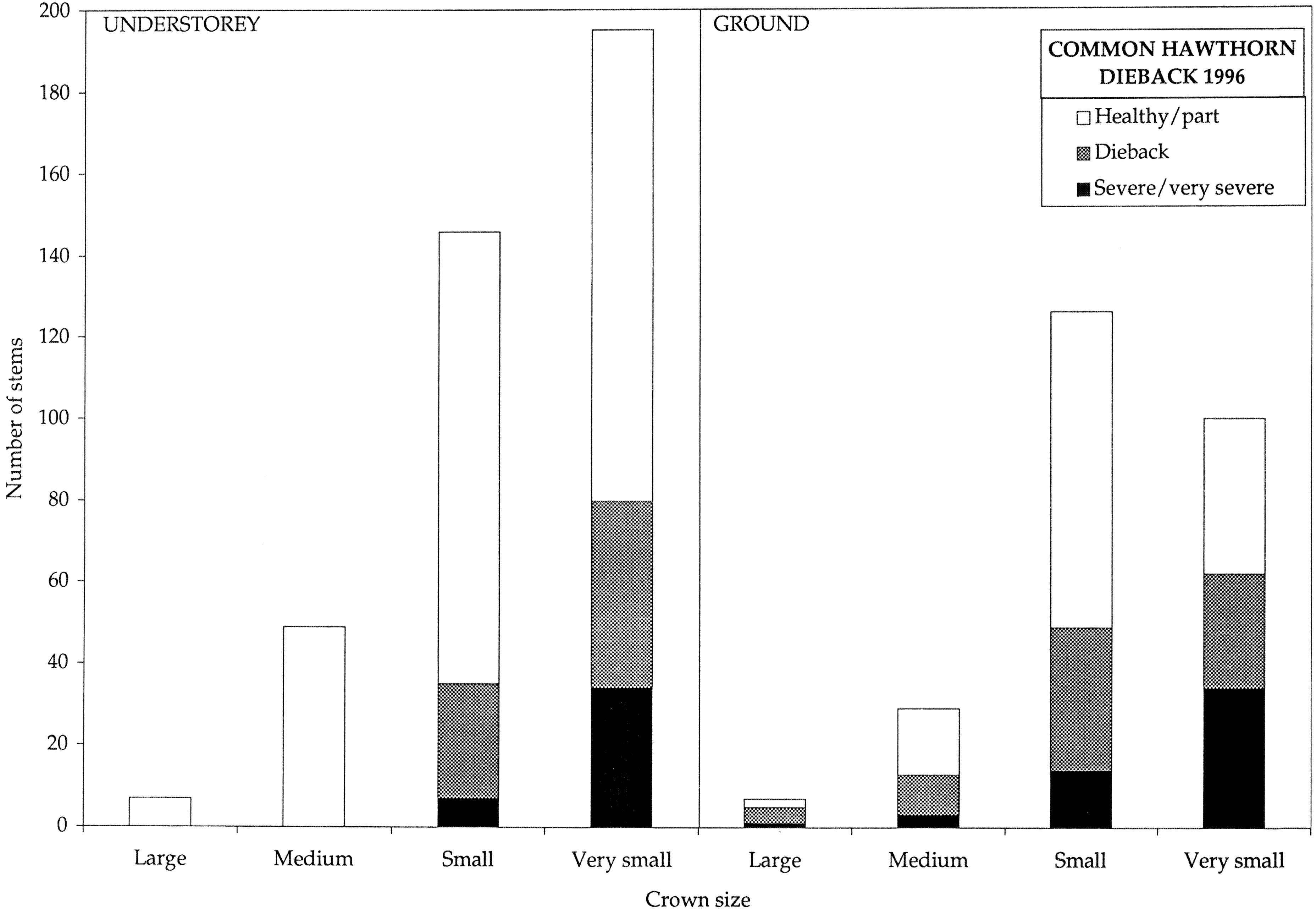


Figure 22: Extent of crown dieback in common hawthorn shown in relation to canopy position and crown size in 1996.

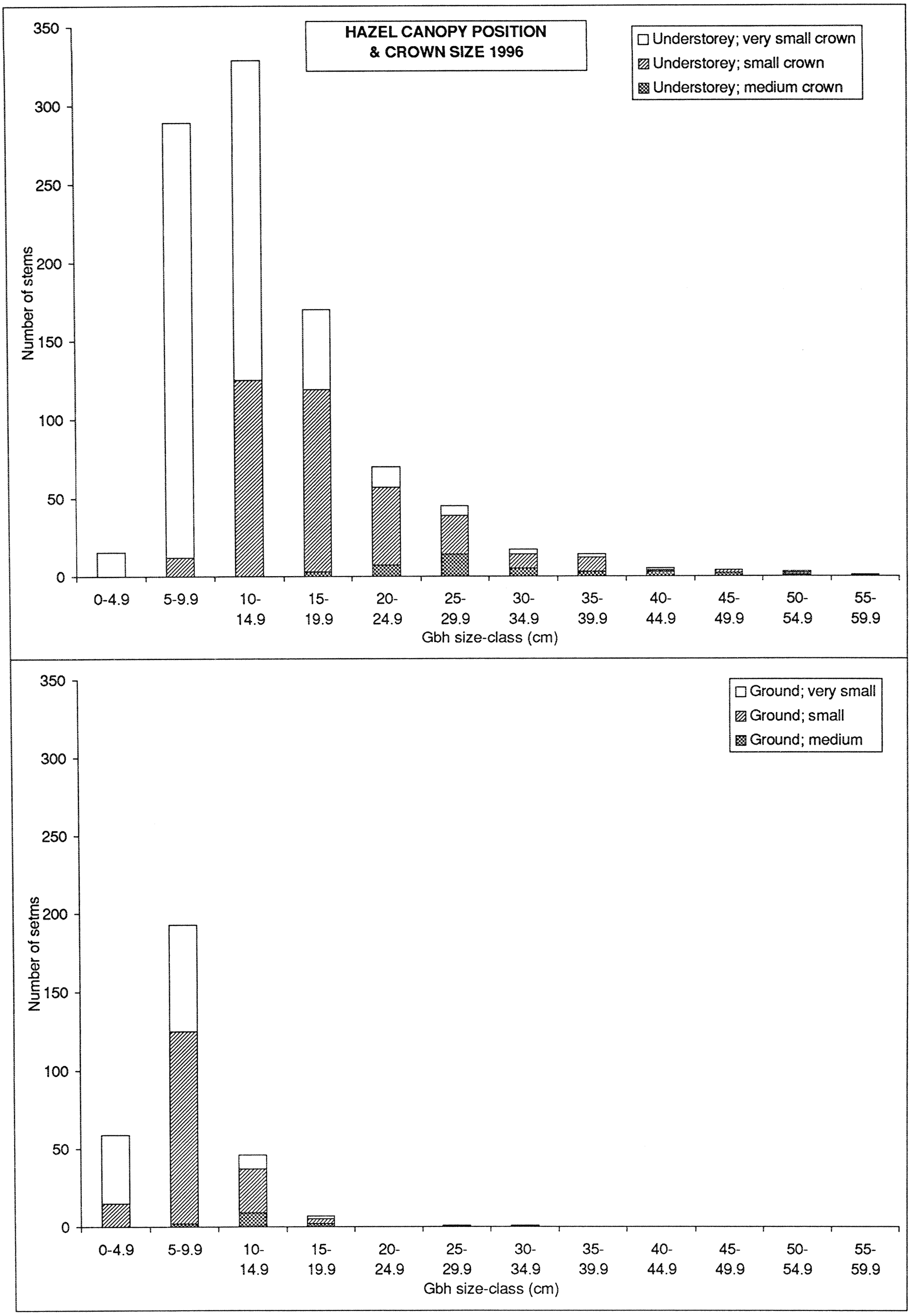


Figure 23: Canopy position and crown size of hazel in relation to gbh in 1996.

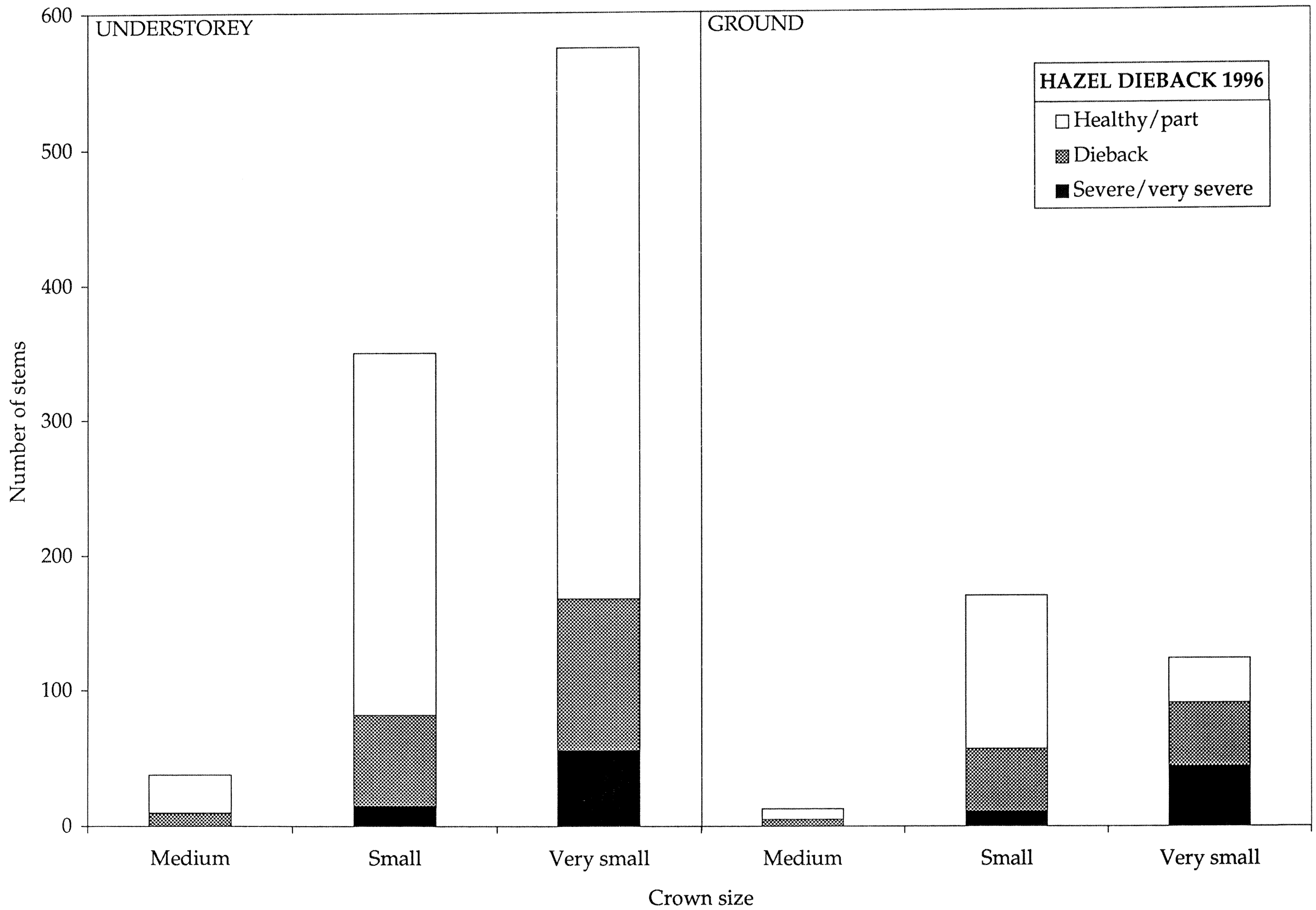


Figure 24: Extent of crown dieback in hazel shown in relation to canopy position and crown size in 1996.

8. Debarking

Lower trunk debarking to stems alive >1.3m height in 1996

	Some debarking	Degree of debarking			No debarking*
		Part	Debarked	Severe	
Midland hawthorn	431	228	115	28	731
Hazel	424	272	126	26	677
Common hawthorn	92	58	31	3	325
Privet	55	10	17	28	8
Ash	51	39	10	2	595
Dogwood	33	14	11	8	14
Blackthorn	17	12	5	0	67
Spindle	5	0	1	4	0
Rose	3	0	1	2	19
Sallow	2	1	1	0	13
Elder	1	0	0	1	11
Maple	1	1	0	0	321
Others	0	0	0	0	55
Total	1115	695	318	102	2827

*(calculated using all recorded stems alive >1.3m in 1996; * excluding stems that were either forks or trunk shoots)*

Table 21: Lower trunk debarking to stems alive >1.3m height in 1996.

The scale of lower trunk debarking to all stems alive >1.3m in 1996 was recorded, but stem forks and trunk shoots that separated some way up the main stem were necessarily excluded from the analysis (table 21). Debarking was a widespread phenomenon with almost 40% of stems at least partly debarked. However over 60% of these were only partly debarked and severe debarking was relatively limited.

Midland hawthorn and hazel had by far the greatest number of damaged stems, but <7% of both were severely debarked. Although there were few spindle, privet or dogwood stems, percentage debarking to these was very high and many stems were at least severely debarked (figure 25).

Damage was largely restricted to stems <20cm gbh and percentage damage tended to increase progressively as stem size decreased (figure 26). The severity of debarking was found to be significantly associated with gbh size-class ($\chi^2 = 61.6$, $p<<0.001$), with severe debarking especially associated with stems sized <5cm gbh.

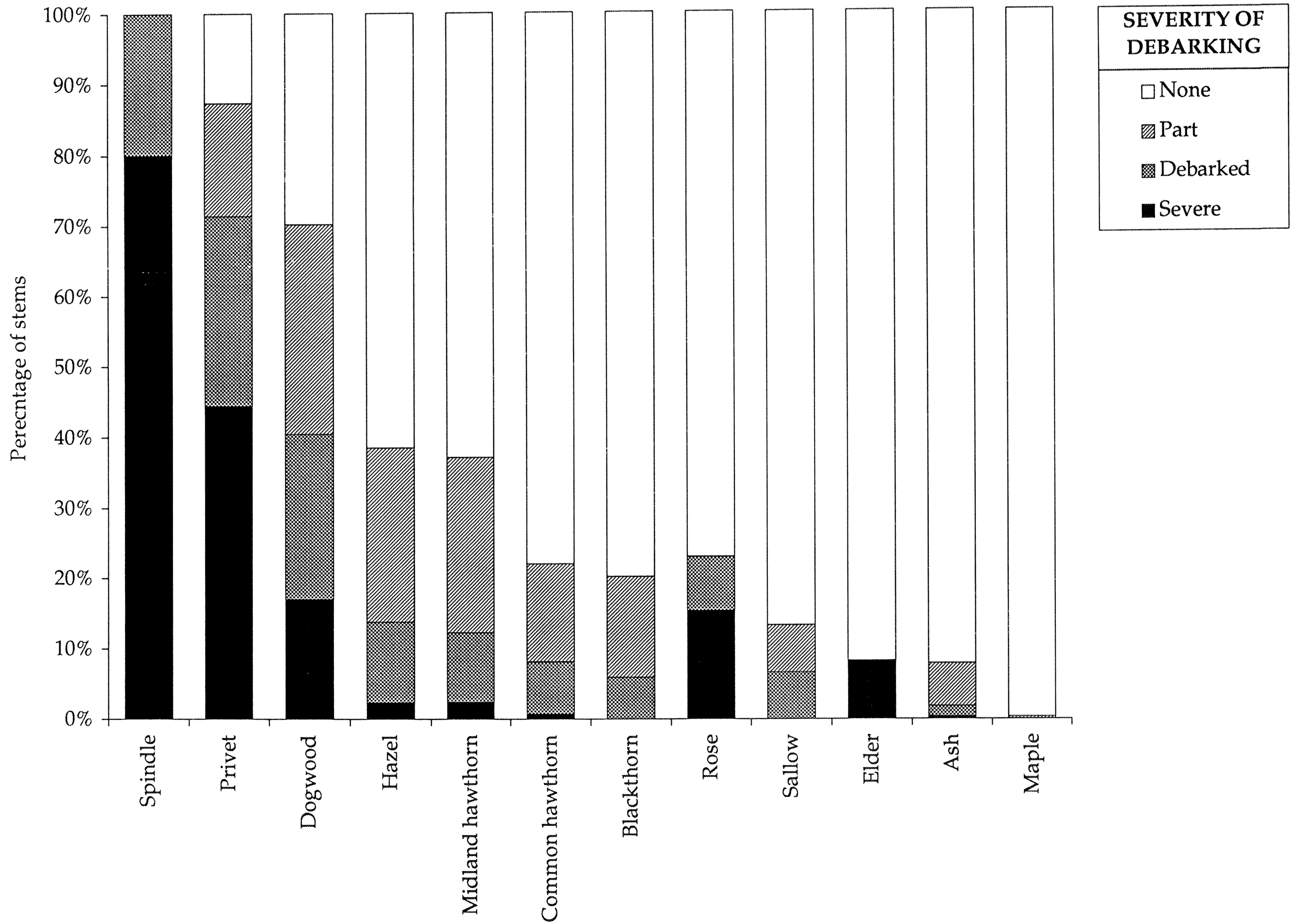


Figure 25: Severity of lower trunk debarking (see text for details) to species in 1996.

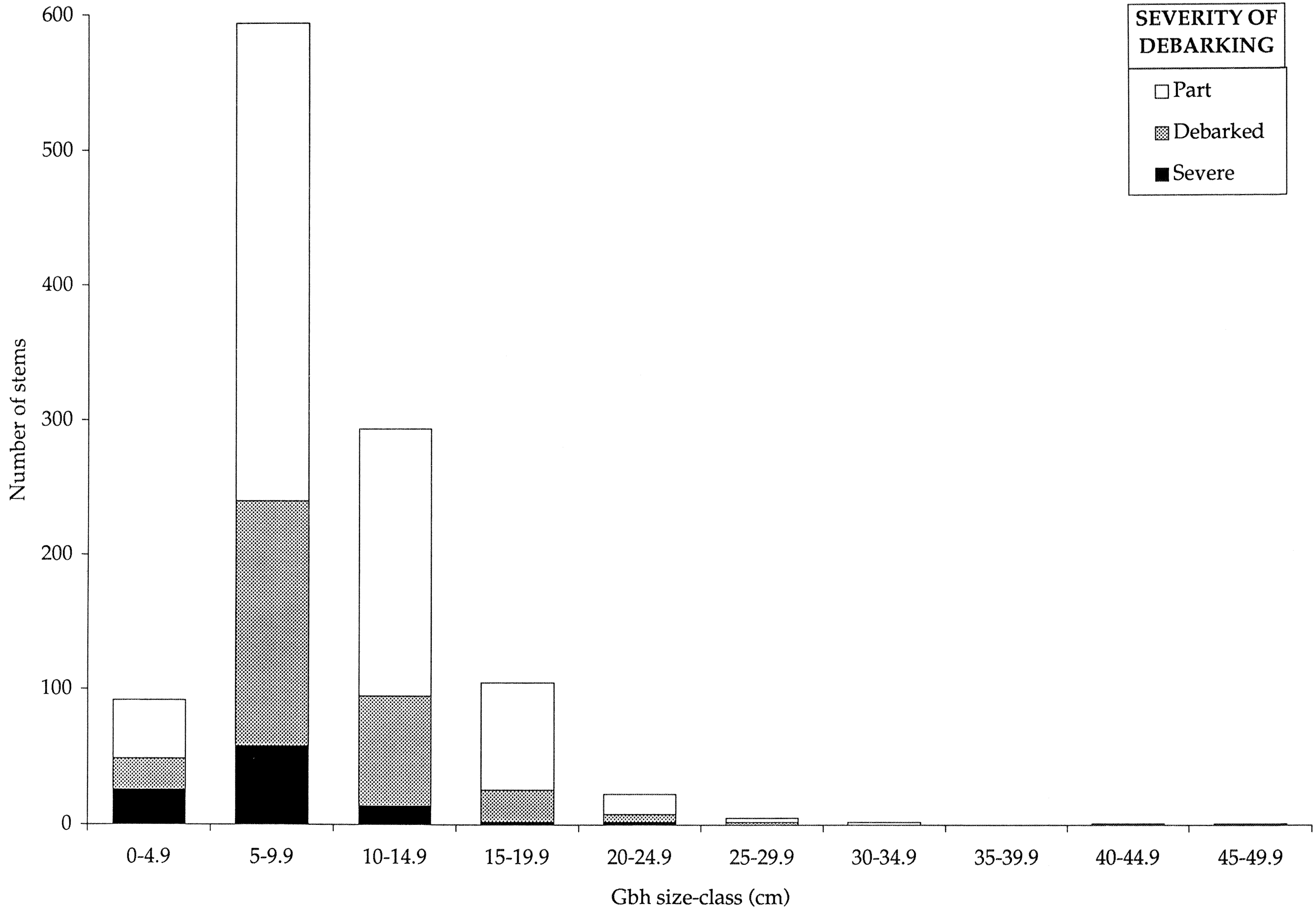


Figure 26: Severity of lower trunk debarking in relation to stem gbh in 1996.

9. DEAD WOOD

Change in basal area of dead standing stems >1.3m height 1985-96

	1985 $m^2 ha^{-1}$	1996 $m^2 ha^{-1}$	Change $m^2 ha^{-1}$
Hazel	1.5	0.7	-0.8
Maple	0.7	0.4	-0.3
Birch	0.5	0.2	-0.3
Ash	0.5	0.4	minimal
Midland hawthorn	0.2	0.1	minimal
Common hawthorn	0.1	<0.1	minimal
Blackthorn	0.1	<0.1	minimal
Oak	<0.1	0.1	minimal
Crab apple	<0.1	<0.1	minimal
Dogwood	<0.1	<0.1	minimal
Elder	<0.1	<0.1	minimal
Rose	<0.1	-	lost
Sallow	<0.1	-	minimal
Privet	-	<0.1	minimal
Unidentified	<0.1	-	lost
Total	**3.6**	**2.1**	**-1.5**

(calculated using all recorded dead standing stems >1.3m height in 1985 and 1996)

Table 22: Change in basal area (m^2 ha^{-1}) of dead standing stems >1.3m height 1985-96.

The basal area of dead standing stems >1.3m height decreased substantially from 3.6 to 2.1 m^2 ha^{-1} from 1985 to 1996 (table 22). Much of this decline was accounted for by the fall in basal area of hazel, maple and birch, with ash alone amongst these major species retaining most of its basal area value in 1985. A wide number of other species also contributed small amounts to the dead standing basal area in 1985 or 1996.

Change in density of dead standing stems >1.3m height 1985-96

	1985 n ha^{-1}	1996 n ha^{-1}	Change n ha^{-1} annum^{-1}
Hazel	657.6	310.0	-31.6
Midland hawthorn	157.6	95.3	-5.7
Maple	88.2	40.6	-4.3
Ash	62.9	35.3	-2.5
Common hawthorn	41.2	25.9	-1.4
Blackthorn	33.5	4.7	-2.6
Birch	14.7	5.9	-0.8
Dogwood	2.9	4.7	+0.2
Oak	1.2	2.9	+0.2
Rose	1.2	-	-0.1
Crab apple	0.6	1.2	+0.1
Sallow	0.6	-	-0.1
Elder	0.6	1.8	+0.1
Privet	-	1.2	+0.1
Unidentified	1.8	-	-0.2
Total	**1064.7**	**529.4**	**-48.7**

(calculated using all recorded dead standing stems >1.3m height in 1985 and 1996)

Table 23: Change in density (n ha^{-1}) of dead standing stems >1.3m height 1985-96.

The density of dead standing stems >1.3m height decreased by half from 1065 to 529 stems per ha between 1985-96 (table 23). There were many species that had dead standing stems present in 1985 and 1996, but few contributed significant amounts towards the total stem density. A decline in density was found in all of the abundant species, and although the rate of decline for hazel was the highest, it still remained as the most numerous in 1996.

Fate and recruitment of dead stems standing >1.3m height 1985-96

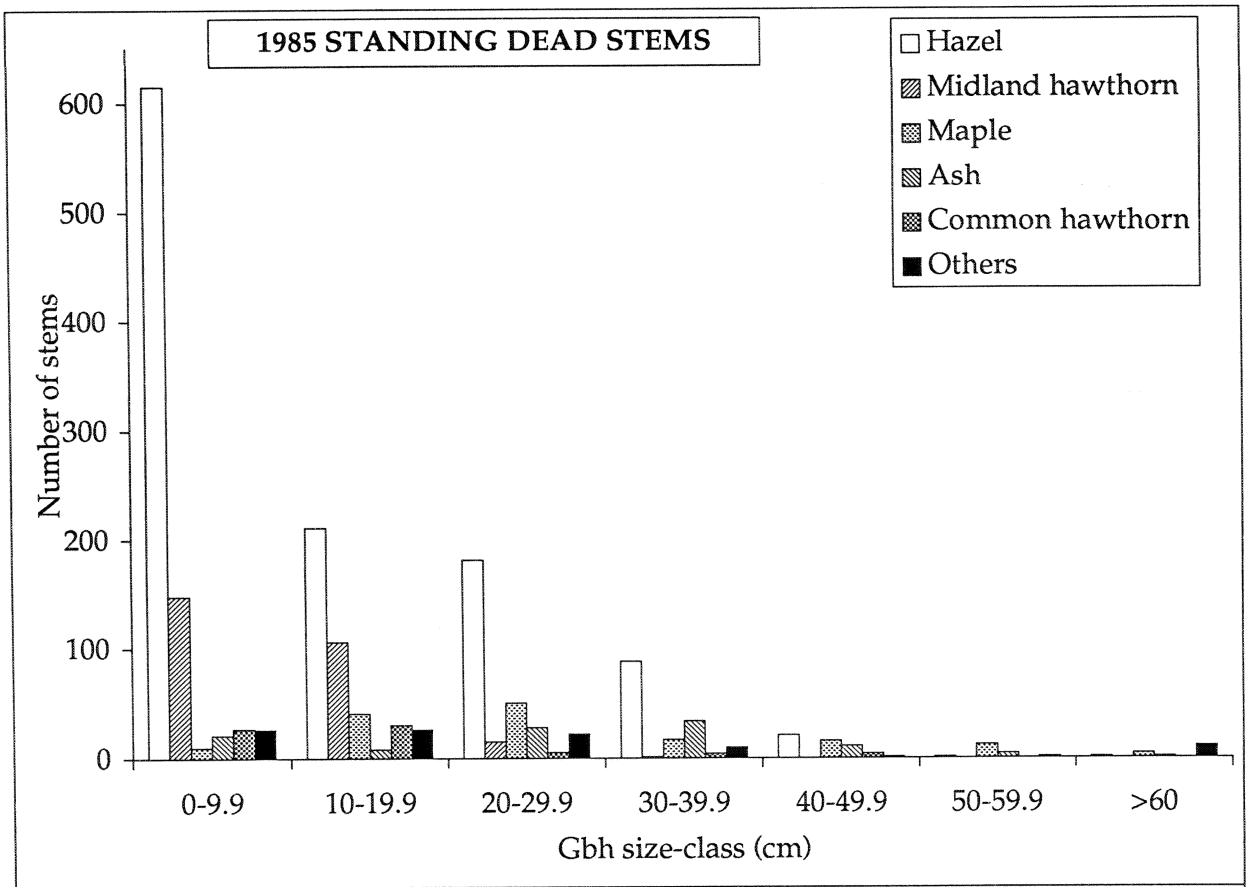
	1985	Fate of 1985 stems by 1996		Recruitment 1985-96	
	Stems dead standing >1.3m	Still dead standing >1.3m	Fallen	Alive >1.3m in 1985	Not present or alive <1.3m in 1985
	n	n	n	n	n
Hazel	1118	102	1016	345	80
Midland hawthorn	268	35	233	124	3
Maple	150	30	120	39	-
Ash	107	23	84	37	-
Common hawthorn	70	6	64	37	1
Blackthorn	57	1	56	7	-
Birch	25	5	20	5	-
Dogwood	5	-	5	7	1
Oak	2	1	1	4	-
Rose	2	-	2	-	-
Crab apple	1	1	-	1	-
Sallow	1	0	1	-	-
Elder	1	1	-	2	-
Privet	-	-	-	-	1
Unidentified	3	-	3	-	-
Total	**1810**	**205**	**1605**	**608**	**86**

(calculated using all recorded dead standing stems >1.3m height in 1985 and 1996)

Table 24: Fate and recruitment of dead standing stems >1.3m height 1985-96.

The survival rate of dead standing stems >1.3m height between 1985-96 was very low amongst all of the more numerous species, and overall only 11% of standing stems in 1985 remainder upright in 1996 (table 24). Period recruitment amounted to almost 700 stems and therefore 77% of the 1996 population were recruited between 1985-96. Most new recruits were hazel or midland hawthorn stems, and many of the hazels had not been recorded at all in 1985 (i.e. they had established and died between 1985-96).

This substantial turnover of dead standing stems between 1985-96 resulted in changes to the size-class distribution. In 1985 the size-class distribution showed a negative exponential decline as stem gbh increased (figure 27). The two major species, hazel and midland hawthorn showed a similar pattern, with small numbers of maple, ash and common hawthorn present in many size classes. Very few dead standing stems >50cm gbh existed. By 1996 the size-class distribution still showed a negative decline with increasing size, but the number of smaller stems had declined greatly. The decline of very small hazel and midland hawthorn stems was especially notable, while a general loss of mid-sized stems was also evident. The number of stems >50cm gbh remained low and only 6 of the 35 stems present in 1985 remained upright.



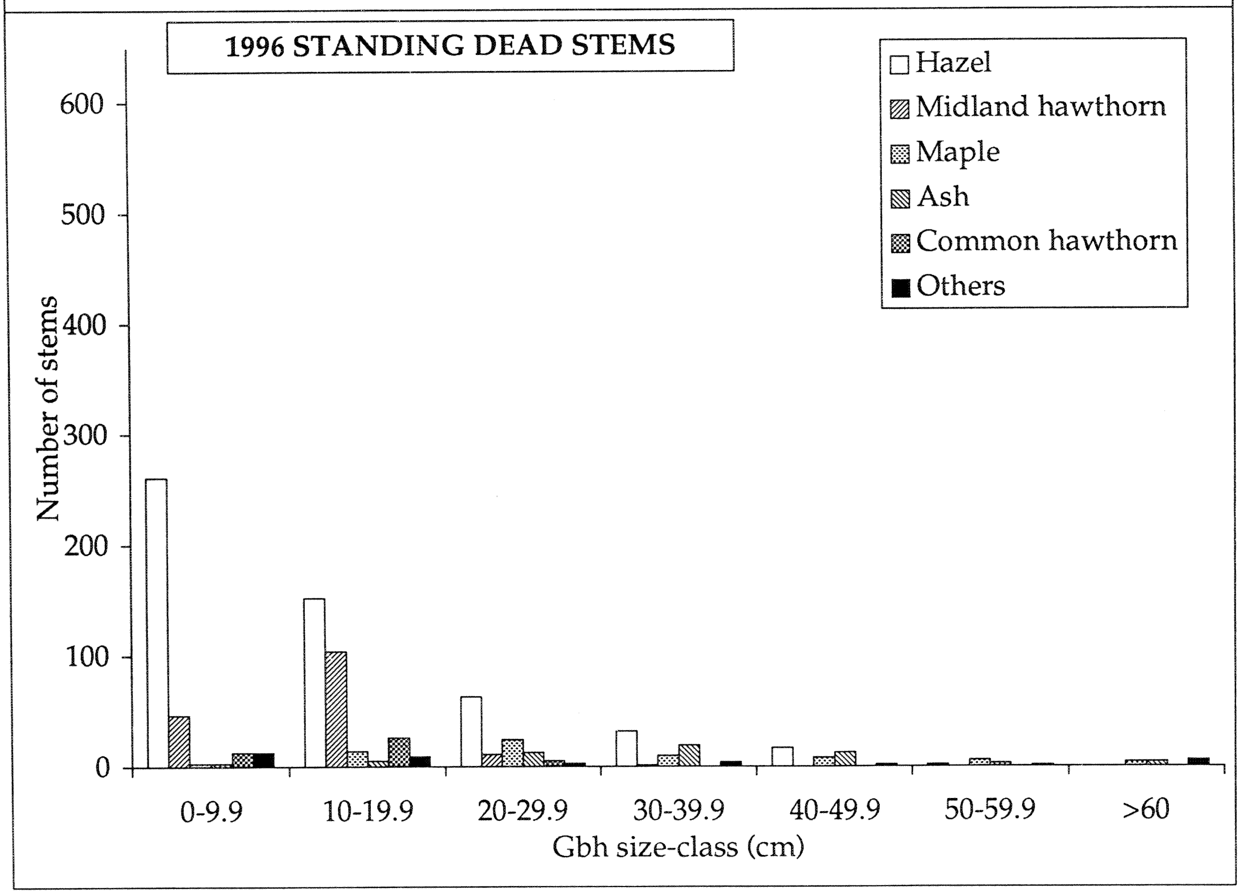


Figure 27: Size distribution of dead standing stems >1.3m height shown in relation to species in 1985 (above) and 1996 (below).

Condition of dead stems standing >1.3m height in 1996

	Hazel	Midland hawthorn	Maple	Ash	Common hawthorn	Others	All
Number of stems	523	161	69	59	43	37	892
Volume (m^3 ha^{-1})	2.9	0.4	3.2	3.1	0.1	2.8	12.5
Height							
0-2.9m	237	95	19	17	21	12	401
3-9.9m	286	66	38	30	22	23	465
10m+	0	0	12	12	0	2	26
Degree of rot							
Solid	403	150	45	41	39	28	706
Part-rotten	112	11	24	18	4	8	177
Rotten	8	0	0	0	0	0	8
Very rotten	0	0	0	0	0	1	1
Bark %							
0-24	2	0	6	2	0	1	11
25-49	7	1	4	1	0	2	15
50-74	43	6	18	9	2	3	81
75-100	471	154	41	47	41	31	785

(calculated using all recorded dead standing stems >1.3m height)

Table 25: Condition of stems dead standing >1.3m height in 1996.

The condition of dead standing stems >1.3m height in 1996 was quantified by approximating snag height, and categorising the degree of rot and amount of remaining bark (table 25). The total dead standing stem volume was 12.5 m^3 per ha, with most snags being either short (<3m) or medium (3-10m) height, with little decay and most bark remaining.

Of the more numerous species, hazel, midland hawthorn and common hawthorn all had mainly short or medium height snags, with little decay and much bark remaining. Maple and ash had more medium height snags and several >10m tall. Loss of large quantities of bark appeared especially common in maple.

Line transect survey of dead fallen stems in 1996

	Ash	Maple	Hazel	Haw-thorn	Black-thorn	Aspen	Birch	Oak	Uniden-tified	All
Number of stems	48	24	19	14	9	2	2	2	2	122
Length (m ha^{-1})	1396	698	553	407	262	58	58	58	58	3549
Volume (m^3 ha^{-1})	10.8	4.6	3.9	2.9	3.6	0.6	1.5	1.5	0.3	29.9
Median diameter (cm)	6.7	6.3	8.0	6.7	7.3	-	-	-	-	6.7
Max diameter (cm)	37.0	16.6	12.0	11.8	23.0	19.1	23.0	25.0	6.4	37.0
Degree of rot										
Solid	15	5	1	8	2	1	0	1	0	33
Part-rotten	21	11	7	4	5	1	1	1	1	52
Rotten	1	5	10	2	1	0	0	0	0	19
Very rotten	3	3	1	0	1	0	1	0	1	10
Bark %										
0-24	7	5	7	10	2	1	0	2	2	36
25-49	8	3	3	0	1	0	1	0	0	16
50-74	15	9	4	2	3	0	0	0	0	33
75-100	18	7	5	2	3	1	1	0	0	37
Origin										
Died standing	26	8	16	10	9	1	0	1	0	75
Windblown stems	17	14	1	0	0	1	0	0	0	33
Small canopy debris	3	2	2	0	0	0	0	0	1	8
1976 drought victim	0	0	0	0	0	0	2	0	0	2
Felled	1	0	0	0	0	0	0	0	0	1
Old stump	1	0	0	0	0	0	0	1	0	2
Unidentified	0	0	0	0	0	0	0	0	1	1

(calculated using all recorded fallen stems attaining 5cm diameter)

Table 26: Results of the fallen dead stem line transect survey in 1996.

In 1996 the quantity of fallen dead wood, and its decay state, bark covering and probable source of origin were determined using the line transect method (table 26). The estimated length and volume were 3549m per hectare and 29.9m^3 per hectare respectively. Most fallen stems were small (<10cm diameter) with limited decay, and had either died standing or been windblown.

Ash was the most abundant accounting for 39% of stems and 36% of the volume. Most ash were small, with only 2 stems >12.5cm diameter and a single larger (37cm diameter) rotten stump. About 25% of stems were well decayed and many had lost over 50% bark. Most stems had apparently died standing but 35% had been windblown.

Otherwise maple, hazel, blackthorn and hawthorn were important, contributing a large number of mainly small diameter stems. Most had died standing, but maple had a number of windblown stems. Decay was well advanced in hazel and maple and all had stems with <50% bark. The cohort of dead birches induced by the 1976 drought had mostly decayed away.

10. CHANGE 1985-1996

General stand changes

The four study transects run through typical wet ash-maple stands (Peterken 1993) that are widespread in the reserve (Steele and Welch 1973), and the study period was 65-75 years since the heavy fellings of c.1920. There were four factors that generally described the change in stand conditions between 1985-96; (i) a more-or-less closed canopy; (ii) an increase in the basal area; (iii) a decrease in the density of living stems; and (iv) low recruitment of new individuals (tables 1-4; figure 2).

This pattern is typical of the *stem exclusion stage* found in unmanaged, relatively undisturbed, young-middle aged, temperate broadleaved stands (Oliver and Larsen 1996; Peterken 1996). As such closed-canopy stands develop, individual stems grow and compete for the limited available resources. Inevitably the less-competitive stems are excluded and consequently die, leaving increasingly large-sized survivors that accumulate more above-ground biomass than is lost through exclusion.

The canopy remains more-or-less closed during this stage as the stem exclusion process is gradual, with surviving crowns rapidly expanding to infill any gaps that are produced. There were some signs of allogenic canopy disturbance in Monks Wood, caused by wind-damage and drought-induced mortality, but overall this has probably only accelerated the change that would have been expected to have arisen through stem exclusion (Peterken 1994).

The stem exclusion process has been statistically quantified by the *self-thinning rule* (Yoda *et. al.* 1963; White 1981), and most transect sections in Monks Wood demonstrated the density-dependent thinning trends that are expected by this rule (figure 3). An implication of the rule is that in mixed broadleaved woods, undergoing predominately self-thinning change, stand development after major disturbance should be comparable and converge over time. Indeed, in terms of basal area range and increment rate (table 1), the observed changes in Monks Wood are closely paralleled by those in the mixed beech-ash-lime stands at Lady Park Wood that were allowed to pass through the same stage of development after heavy felling (Peterken and Jones 1987).

Recruitment during the stem exclusion stage is also restricted by intense competition for ground-layer resources and heavy canopy shading at the woodland floor. However, with the establishment of a large number of advanced regeneration ash saplings in 1985 (table 5; figure 4), there was some indication that the wood was entering into the *understorey reinitiation stage*, when, several decades after the stem exclusion stage begins, a low stratum of herbs, shrubs, and advanced regeneration invades the woodland floor (Oliver and Larsen 1996). However a dense mixed understorey has persisted in many parts of Monks Wood, and the most vigorous advanced regeneration, principally of ash, was found in areas of relatively weak understorey growth and especially where large canopy birches had died, presumably induced by the 1976 drought. Therefore the potential natural transition of the stands appeared to have diverged according to the endurance of particular conditions, which probably established when the stands first initiated.

Performance of the major species

Ash

Ash was the most numerous and widespread tree species in 1985, accounting for about half of the total stand basal area (tables 2-3). It dominated most sections, but was less abundant along transect 18 where it was patchily distributed (Peterken 1994). The stem population was strongly influenced by past management; much was either coppice regeneration that had established after the early 20th century fellings or standards/stored coppice that had been retained at this time (figure 4). However the very large number of small advanced regenerants appeared to be a reflection of recent natural stand transitions.

The superior competitive ability of ash was clearly demonstrated. By 1996 it accounted for over 80% of all canopy stems and had singly amassed over 90% of the basal area increase between 1985-96 (table 2 and 20). This increase was principally due to limited stem mortality and moderate growth of middle-large sized stems (c.2mm wide average annual growth rings) (tables 4, and 6-8; figures 4 and 10). Interestingly the growth of ten ash stems in Monks Wood between 1964-68 recorded by Steele (1973) were very similar to those recorded in this study.

The performance of the ash population was strongly influenced by the exclusion process, although windblow knocked over the largest stems that died. Progressively smaller sized stems had proportionally greater mortality, tended to be in lower stratificatory layers, have smaller crowns and more dieback, and significantly poorer increment rates (tables 6-8; figures 7, 13, 15 and 16). Both exclusion from the upper canopy and crown reduction appeared critical in inducing mortality, as indicated by the moderate persistence of stems in the understorey (table 4 and 20).

The historical predominance of the stem exclusion process was evidenced by the size distribution of the early 20th century regeneration cohort. The most competitive stems appeared to be sized about 100 cm gbh, whilst the least competitive were only about 10cm gbh (figure 4). The change in the ash sample studied by Welch (1994) from 1964-93 shows the expected gradual size-class progression of ash, although the predominance of oak in this study plot appears to have suppressed the growth of ash.

In 1996 remarkably little evidence, literally, could be found of the ash seedlings that formed the advanced regeneration cohort in 1985. This was probably due to browsing by muntjac deer (see below).

Maple

Maple was a sub-dominant major tree in 1985 and accounted for about 20% of the total stand basal area in 1985 (tables 2-3). It was patchily distributed and in a few areas dominated the stand basal area (Peterken 1994). Virtually all stems appeared to be from coppice regeneration that had established after the early 20th century fellings, together with a few standards/stored coppice stools that were retained at this time (figure 5).

By 1996, the maple basal area had declined substantially and stem density moderately (table 2-3). The basal area decline was caused by the loss of a few large and several middle-sized trees, the largest of which were mainly killed by windblow, and the poor compensatory growth of most surviving stems (<1mm wide average annual growth rings) (tables 4, 6 and 9; figures 5 and 11). The ten maple stems recorded by Steele (1973) between 1964-68 grew at similar rates.

The exclusion process significantly effected maple performance, although it was clearly better able to endure relegation in to the lower canopy layers. In general, progressively smaller stems tended to have proportionally greater mortality, be in lower stratificatory layers, have smaller crowns, more dieback, and significantly poorer increment rates (tables 6, 9 and 10; figures 4, 11, 15 and 16). However most of the 1996 population survived in the lower layers and many had medium or large crowns with little dieback (table 20; figures 15-16). This infers that maple mortality was moreover connected with crown reduction.

Growth patterns in the lower layers were moreover related to crown size than stratificatory layer (tables 9-10). Nevertheless growth was clearly much greater in medium crowned canopy stems, and the stratificatory relegation of most stems had resulted in the poor growth of the species between 1985-96 (tables 9-10). This relegation appears to be due to lack of vertical growth, as many lower canopy maples had medium or large crowns that were clearly not a product of crown reduction from the upper canopy (figure 15).

The prolonged effect of the exclusion process was visible in the size distribution of maple stems, with the early 20th century regeneration cohort now apparently extending from about 10-100cm gbh stems, although the modal class was 20cm smaller than ash (figures 4-5).

Oak

In 1985 oak was present in small numbers as scattered, mostly large girth, standard trees which had been retained during the early 20th century fellings (tables 2; figure 6). By 1996 oak basal area had increased moderately as mortality had been low and growth moderate (1-3mm wide average annual growth rings) (tables 2, 4, 6 and 11; figures 6 and 12). The growth of ten oak stems in Monks Wood recorded between 1964-93 by Steele (1973) and Welch (1994) closely matched the 1985-96 rates (figure 6).

The exclusion process also significantly influenced oak performance. Smaller stems tended to have greater mortality, be in the lower canopy layers, have smaller crowns, more dieback, and significantly poorer increment rates (tables 6, 11 and 12; figures 6, 12, 17 and 18). Exclusion into the lower canopy layers appeared to be especially critical in inducing mortality, as survival in these layers was notably low (table 20). Although the trees were undoubtedly of unequal size in the early 20th century and growth rates appear to have been very variable, the exclusion process has undoubtedly truncated the size distribution of surviving trees (figures 6 and 12).

Midland and common hawthorn

Hawthorn individuals were designated as either midland or common hawthorn, but hybridisation was abundant and these categories included hybrids which appeared to more closely resemble one species than the other.

In 1985 midland hawthorn was the most numerous and accounted for the most basal area of all understorey species (table 2-3). Common hawthorn ranked third most important in terms of basal area and density (table 2-3). Both were widespread, typically multi-stemmed coppice, and in substantial areas formed a dense lower layer of intertwined arched stems. Both stem populations appeared to be dominated by early 20th century regeneration, with a few larger stems, especially of common hawthorn, that probably originated before this time (figures 7-8).

By 1996 both species had increased their basal area moderately, and stem survival had been relatively high, including many stems which had fallen over but still remained alive (tables 2 and 4). Indeed, 48% of the midland hawthorn and 40% of common hawthorn stems were recorded in the ground layer in 1996, principally from arched over stems and collapsed stools (table 20). Although both acquired a large number of new trunk shoots or stem forks, most of these were probably present but not recorded in 1985 (table 4).

There was evidence of the progressive exclusion of smaller sized hawthorn stems; in general they had proportionally greater mortality, tended to be in the lowest canopy layer, have smaller crowns, and much more dieback (figures 7-8 and 19-22). Although growth was not significantly related to stem size, on average very small crowned stems grew poorly, small crowned understorey stems grew better, and larger crowned understorey stems grew most rapidly (table 13-17). This exclusion pattern explains the extended size distribution of the supposed even-aged early 20th century regeneration (figures 7-8). Interestingly, the average growth of common hawthorn was significantly greater than midland hawthorn, but the mean difference only amounted to 0.08 mm width on an annual growth ring (table 13).

Hazel

Hazel was the other major understorey species in 1985, ranking second in terms of basal area and stem density (tables 2-3). It was widespread, typically as multi-stemmed coppice individuals, and especially abundant in central sections of transect 9, 14 and 18, and the beginning of transect 30. Again the stem population appeared to be dominated by early 20th century regeneration (figure 9).

By 1996 the hazel population had declined substantially; stem density had fallen by 30%, and its basal area and rank had both dropped (tables 2-3). Indeed only about half of the stems alive in 1985 survived to 1996, and although the recorded compensatory recruitment of new stems appeared to be mostly genuine, a large number of recruiting stems were already dead by 1996 (table 4 and 24). Despite these losses hazel remained co-dominant with midland hawthorn in the understorey layer in 1996 (table 20).

The decline in hazel appeared partly due to the exclusion of smaller sized stems, which tended to be in the lowest canopy layer, have smaller crowns, and more dieback (figures 23-24). Also, although growth was not significantly related to stem size, on average small crowned stems in the ground layer grew very poorly, small crowned understorey stems grew better, and medium crowned understorey stems grew most rapidly (table 13 and 18-19). This pattern explains the extended the size distribution of the supposed even-aged early 20th century regeneration, although some of the smallest stems have certainly recruited recently (table 4; figure 9). However a more extensive decline was evident, with proportional mortality high across all size classes as many larger stems died (figure 9). This decline in hazel was already in evidence in 1985; hazel accounted for 40% of the total dead standing stem basal area and dead standing hazels >30cm gbh were abundant (table 22; figure 27). Interestingly this decline of larger stems does not coincide with poor growth performance in hazel; average growth was significantly greater than either hawthorn species and amounted to about 0.2mm width on an annual growth ring (table 13).

Possible impacts of muntjac deer

During the mid-1980s the number of muntjac deer in Monks Wood increased to produce an unusually large, dense and persistent population (Cooke 1994). The species is a highly selective feeder, having caused massive damage to woody regrowth in coppiced plots and ride-margins, even where protective fencing has been erected, and especially to slow-growing dogwood, privet, field maple and elm, but also hazel and ash (Cooke 1994).

Detecting the impact of muntjac browsing in this study is problematic because of the influence of natural processes. The high percentage loss of dogwood, privet, bramble, aspen, and guelder rose (table 4) can be attributed, at least in part, to browsing, but high mortality of light-demanding short-lived species is typical during the stem exclusion stage (Peterken 1996). However the destruction of ash, blackthorn, bramble, dogwood and midland hawthorn stems alive <1.3m high, and loss of small sized ash stems (<10cm gbh), was so severe, left no physical remains, and coincided with such limited recruitment, only muntjac browsing could realistic explain these changes (table 5; figure 6). Destruction of privet stems alive <1.3m high, although considerable, suggested that this species was more resilient to short-term browsing, while the large number of recruits <1.3m high were clearly created by destructive browsing of taller bushes (tables 4-5).

The extensive lower trunk debarking recorded in 1996, which included both recent and older debarking, was also attributed mainly to browsing, although other species than muntjac could be implicated (table 21). The damage was mostly in the form of small discrete patches up to 1m high on hawthorn and hazel stems. However there were several forms of selectivity; percentage damage to spindle, dogwood and privet was very high, damage severity progressively increased as stem size decreased, and stems <5cm gbh were especially severely debarked (figures 25-26).

Changes in the dead wood component

Most of the recorded dead wood was short, small-medium diameter, hazel, maple, birch or ash, and large stems were scarce (tables 25-26; figure 27). Although dead standing stems in 1985 were relatively numerous, the basal area amounted to about just 1% of the total stand basal area (tables 20-21). By 1996 the basal area had declined further and the density almost halved (tables 2 and 22). The higher basal area in 1985 was mostly accounted for by increased amounts of hazel, maple and birch, the latter, at least, due to drought-induced mortality of larger trees (table 22).

The basal area levels of 2.1-3.6m^2 per hectare in Monks Wood were far lower than levels approaching 10 m^2 per hectare that can amass in non-intervention woodland in Britain (Mountford 1997). In 1996 the total standing and fallen dead wood volume was estimated at 42m^3 per hectare (tables 25-26), slightly lower than the 46-132m^3 per hectare reported from various natural old-growth temperate broadleaved forests (table 8.3 in Peterken 1996). The estimated volume of fallen dead wood at 29.9m^3 per hectare was within the range of 16-36m^3 per hectare given for similar aged derelict coppice sites in Britain, but far lower than the 75 m^3 per hectare from undisturbed areas of the primeval Bialowieza forest in Poland (Kirby *et. al.* 1991; Kirby 1992). The estimated dead wood length at about 3500m per hectare was slightly above the range of 1133-3021m per hectare for similar aged derelict coppice sites in Britain (Kirby 1992).

The low accumulations of standing dead wood appear to be related to a very rapid turnover of stems. Only about 10% of dead standing stems in 1985 remained standing in 1996, a high percentage of stems that died between 1985-96 had already fallen by 1996, and a number of dead standing stems in 1996 were period recruits that had already died (table 24; figures 4-9). The considerable input of material made to the woodland floor between 1985-96 is confirmed by the estimated length of fallen dead wood in 1996, but the volume still remained relatively low (table 26). Certainly many of the fallen stems were small sized and would therefore contribute little to dead wood volume (table 26; figures 4-9 and 27), but rapid stem decay on the woodland floor could also be important. This is suggested as only 1% of standing stems had advanced decay and 3% had lost at least half of their bark, whilst 24% of fallen stems had advanced decay and 43% had lost at least half of their bark (tables 25-26). Decay in hazel and maple was especially advanced, and most birches killed by the 1976 drought had rotted away (table 26).

11. Monitoring in Woodland Reserves

Experience of long-term recording in Monks Wood NNR provides some guidance for environmental monitoring generally. Four possible approaches may be recognised:

- Historical records can provide a truly long-term context for modern changes. Hooper's account in Steele and Welch (1973) gathered together what was known of past management conditions. This information was combined with information supplied from the reserve records by Maurice Massey to calculate changes in the gap creation rate over 200 years and the extent and condition of permanent open space (Peterken 1996, p.402). A substantial difference was revealed between traditional management and reserve management, which was probably a contributory factor in the decline of butterflies.

- Change can be detected using records that were not initially intended for monitoring. As far as we know, the observations made by R.C. Steele were regarded as a one-off exercise, forming part of a programme to characterise semi-natural woods. Thirty years later they were used to assess changes in the ground vegetation and stand structure (Crampton 1996; Stutter 1996). The changes were already recognised, but the old records enabled them to be quantified and substantiated scientifically.

- Permanent plots can be observed at intervals. This is the basis of the present study. The strength of permanent plots is that real places are under observation and real change can be identified. They can be used to demonstrate change to visitors and new site managers. A quick check on changes can be made by recording a sub-sample, as GFP did in 1994 for the Monks Wood 40th Anniversary Symposium (Peterken 1994). Photographs can supplement the record and be used for demonstration and detecting unexpected changes. The weakness is that samples may not be representative of the reserve as a whole.

- Surveys based on regular, random or stratified-random samples can be repeated. These are likely to be truly representative and enable reserve-wide change to be quantified, subject to the degree of variance obtained. Such samples are not available for Monks Wood, though the Oxford M.Sc. re-surveys (Crampton 1996; Stutter 1996) were tantamount to this form of sampling, in so far as the exact position of the plots from the 1960s could not be found.

Several important general features emerge:

- The events or changes we wish to monitor are unpredictable. When the reserve was founded nobody anticipated the loss of butterflies, the arrival of Dutch Elm Disease, the 1976 drought, looming nitrate rain, the spread of muntjac and the transformation of the ground vegetation. Any monitoring system set up at the outset would have had to incorporate generalist elements to be useful. If it had been based only on measuring particular features precisely, there is a chance that these would have not been relevant to modern concerns.

- Funding for this recording came from outside NC-NCC-EN. It is generally difficult for organisations to commit funds many years ahead and in practice it is often necessary to take advantage of opportunities from outside and at short notice.

- The records survived (and awareness of their whereabouts) as a result of the initiative of individuals. EN, like NC and NCC before it and other organisations, had no scientific archive (EN does now has a central sites file registry where data can be marked for long-term retention). It is likely that several other data sets from the early years of research in Monks Wood would have been valuable if they had survived.

- The period covered by the present study happened to coincide with the burgeoning of the muntjac population, but not all intended long-term studies have the 'luck' to be interesting from the outset. Most do not become interesting for, perhaps, 25 years, by which time initiators have probably lost interest.

Accordingly, we suggest that several points are worth considering when planning monitoring:

- Keep the records that happen to be made, even if they are not seen as part of the monitoring plan. Even simple observations become valuable many years later.

- Maintain an institutional memory. It is possible for records to survive, but for none of the present post-holders to know this.

- Make multiple copies of data and deposit them in different places. Interested individuals have proved most reliable.

- Establish a small baseline allocation of resources each year for recording. Long, 'thin' funding is the most difficult to maintain.

- Record basic features in a simple fashion. In woods this means recording the trees, understorey, and ground flora layers. Transects have proved easier to find than scattered plots.

- Supplement the systematic record with photographs, which provide an unedited record in which unexpected changes may be apparent.

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