The Economic Implications of Deer Damage

A review of current evidence

Final Report for
The Deer Commission for Scotland

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Summary

1. The lack of direct evidence for the economic implications of damage in forests has generated uncertainties surrounding the need for deer management. This report was commissioned to identify existing data and information requirements to estimate the costs of deer damage. Data was obtained from both published and unpublished sources on the levels of various forms of deer damage, the effects of damage on growth and timber quality and the consequences of damage to timber yield and ultimately revenue losses.

2. An analytical method was developed to estimate accumulated bark damage at felling age from a single damage assessment. Estimates of accumulated damage ranged from 0.7% and 23% for Sitka spruce in Galloway and Argyll respectively and 41% for lodgepole pine in Galloway.

3. The extent of stain and decay developing from bark wounds is dependent on wound size, with larger wounds being associated with relatively more stain and decay. However, not all wounds become infected with decay-forming microorganisms, possibly because few species sporulate in winter when most deer damage occurs.

4. The presence of stain in a damaged log is not in itself evidence for structural deterioration. Nevertheless, staining is usually regarded as an indication of potential decay in the timber industry and results in logs being downgraded.

5. Making use of information on average wound size and position and the relationship between wound size and stain extension, the length of stained timber was estimated at 1.13-1.40m for Sitka spruce at felling age.

6. A yield model and assortment program was used to estimate financial losses. On the assumption that the stained section is sold for pulp and the remaining log unaffected, this amount of stain would equate to a financial loss of 0.03 to 1.03% for the levels of accumulated bark stripping damage estimated for Galloway and Argyll respectively. The loss would increase to 0.06-2.02% if each damaged log were downgraded from green to red.

7. Browsing on Sitka spruce has been found to impose an average delay in height growth of approximately one year in Scotland. Much longer delays have been recorded on other species and locations. If maintained until the end of a rotation, a one year delay in growth in Sitka spruce could result in a revenue loss of 3.4%.

8. The survival of young trees following browsing is complicated by interactions with competing vegetation. Under low browsing pressure, survival rates can be higher than within a fenced compartment. Nonetheless, under-stocking is commonplace in Scottish forest conditions resulting in significant costs for beating-up, at least some of which can be attributed to deer.

9. Leader browsing can result in reduced log size and poor stem form. The loss of revenue will depend on the relative sizes of each forked stem. At the levels at which multiple stems have been reported for Sitka spruce in Scotland, losses were estimated to range from 0.8-8.4%.

10. Estimates of revenue loss suggest that browsing is likely to be a more serious form of damage than bark stripping. However there is a lack of data directly relating growth loss, survival and

poor stem form to timber yield loss. As a result, estimates of revenue loss from browsing remain speculative.

11. The relative loss of revenue from deer damage is sensitive to variation in stand growth rate, rotation length, and timber product prices. In the case of bark stripping, it is also dependent on the visibility of the damage and decisions taken at harvesting on product allocation. As a result, efforts taken to limit revenue loss through deer management are likely to be only partially effective.

12. In view of the fact that much of the cost of deer control can be offset against revenue from venison, culling appears to be far more cost effective option than fencing, which could cost in the region 10-30% of yield for Sitka spruce. Estimates of the cost of browsing on Sitka spruce suggest that fencing is unlikely be a cost-effective measure for preventing damage, unless it is to be applied in an area where little or no deer control can be carried out.

13. Sitka spruce is resilient to most forms of damage. However several other species (Scots pine, oak, Norway spruce, larch and Douglas fir) are more sensitive and are now being planted more extensively. Deer management and tree protection will therefore assume greater signifcance where these tree species are being established.

14. Recommendations for further research are given.

Contents

1. Introduction

1.1 Objectives and methods

Deer populations remain at high levels in much of the UK and are continuing to increase in some areas. There is growing concern for the levels of damage occurring in many parts of the country. Many landowners however continue to show reluctance to reduce deer numbers and it is clear that more evidence of the economic implications of deer damage are needed to justify the increased effort required to control deer. The problem is compounded by lack of knowledge on the relationship between damage and the amount of revenue ultimately lost. In view of the long delay between damage and harvesting, little direct information is available to illustrate exactly what kind of relationship exists between damage and yield.

Various research and survey projects on the impact of deer have been carried out in the past, many of which are relevant to this problem. However the results have not all been published and many are still continuing. Briefly, this work has addressed the following aspects:

- In response to concern about increasing levels of deer damage in the 1970's, wide scale surveys of damage were undertaken. These led to the development of a deer damage assessment method for use at the stand scale (Melville *et al* 1983)

- Work was undertaken to assess the relative vulnerability of trees of differing species, age and provenance to both browsing and bark stripping. The results have been summarised in recent reviews (Mitchell *et al* 1977; Gill 1992)

- The relationship between wounding, stem decay and discolouration has investigated in Sitka spruce and lodgepole pine. Some of the results of this were reported by Gregory (1984; 1986).

- Assessments of the effect of browsing on growth and stem form. This topic was reviewed in Gill (1992b) and recent results have been published by Welch *et al* (1995). Research on this topic is being continued by Forest Research.

This report was carried out to review the information available that is needed to estimate the revenue loss from deer damage. To do this, it is necessary to compile information on the following:

- Estimates of the proportion of trees in a stand that are damaged, for each form of damage (browsing, bark stripping and fraying).
- Measures of the severity of damage (e.g. mean wound size) or the frequency of damage to individual trees.
- For each type of damage, information is needed of the impact of damage on tree survival, growth rates and on timber quality.
- Information on timber prices and the revenue that could be earned from an undamaged stand.
- A yield model which provides estimates of timber volumes for stands of various

age classes and growth rates.

- An assessment of how damage might affect allocation of timber into various products (sawlog timber pulp etc.) or grading into logs that command different prices.
- Information on the costs of various measures (beating up, deer control and fencing) which are deployed to alleviate damage.

At least some information is available on all these components of the process that could result in revenue loss. However there is relatively poor information on some aspects of the problem and for some tree species. Nonetheless we have approached the problem by attempting estimates of the scale of possible revenue loss to highlight strengths and weaknesses in the current data set. Estimates have focussed on Sitka spruce, not only because it is the most abundant species in Scotland, but also because it is the only one for which a yield model which allocates timber volume into products is currently available. To aid comparison between different forms of damage, estimates of revenue loss have been based on Yield class 12 and 16 stands of Sitka spruce for rotation lengths of 45 and 60 years, on an un-thinned management regime. Different yield classes and rotation lengths were chosen to explore some of the implications of variations in productivity and management.

1.2 Sources of Information

Information gathered when preparing this report has been obtained both from existing published sources as well as a number of surveys and experiments that have been carried out by the Forestry Commission. The results of some of these experiments have not been published and others are still in progress. A brief description of these experiments is included here to outline the objectives and methods involved

Author/expt number	**Date**	**Survey or experiment description**
Holloway, C.W.	1968	**Survey of bark damage by deer in Keillour Forest, Perthshire**. Damage was assessed in 6 plantations in random plots and recorded by species age and year. A sample of trees were felled to assess wound healing and infection.
Stewart, D.	1977-81	**Galloway deer damage survey.** Damage (mainly bark stripping) was assessed in four years (1977,79,80,81). One hundred trees were inspected at 325 random locations each year, making a total sample of approximately 120000. Both old and new damage was recorded by tree species, age and agency.
Melville, R.	1977-79	**Surveys of deer damage in Scotland.** Surveys to assess the severity of browsing damage on restocks. A total of 116 compartments were assessed from 12 forests and for 5 tree species.
Y14/26 (Ongoing)	1978-	**Experiment to assess the effects of bark wounding.** 300 trees of Sitka spruce and 300 Lodgepole pine had bark removed to assess the effect on growth and timber quality. Treatments were 0 (control), 25%, 50%, 75% and 90% of circumference removed. One third of the trees were felled in 1990 to assess the effects on growth and severity of stain.
Y14/63	1987-1990	**Experiment to assess the effects of browsing on growth of conifers** In each of 14 sites in the UK, 200 trees (50% protected with tree guards) were monitored for damage and growth for up to 4 years after planting.
Y14/72 (Ongoing)	1993-	**Experiment to assess the effects of browsing on growth, survival and stem form under varied deer pressure.** Trees of 8 species (Oak, birch, ash, alder, Scots pine, Norway spruce, larch and Douglas fir) were established in three enclosures, (two containing roe deer, one control) and monitored since planting in 1993. A total of 576 trees were planted in each enclosure. The enclosures contained a density of 42('medium') and 75('high') deer/km2. Each enclosure contained a relatively large proportion of restock habitat and could support high deer numbers.

2. Bark Stripping and fraying

Susceptibility to bark stripping is strongly associated with the age, size and species of trees. Damage can begin when the main stem becomes rigid and accessible (from 4-5 years old) and ends when the bark is too tough and thick to remove. In some species (notably spruces) the side branches provide some protection, so bark stripping may not become significant until they die or are removed by brashing (Gill 1992a).

Bark stripping is only done by the larger deer species (red, sika and fallow deer), although sometimes fraying damage by roe deer is confused with stripping. Bark stripping can arise at any time of year, although peaks of stripping activity typically occur in early December to mid-March (Welch *et al* 1987; Gill 1992a). The bark is usually removed from the main stem 50-100cm above ground level (mean ~ 80cm; upper limit ~150cm) (Welch *et al* 1988). Larger wounds tend to be found on larger trees, with bark stripped trees often grouped together in a particular part of a forest or stand. Individual trees may also suffer repeated bark stripping, and the multiple wounds may be visible as several separate areas of damage or coalesce into one major wound.

Fraying is caused by the action of rubbing antlers up and down the stem of saplings and is most commonly associated with mating behaviour. Roe deer tend to select younger and smaller trees than red deer (Gill 1992a). Sika deer also have the habit of scoring pole-sized or mature trees with their antlers, which may cause serious damage locally. In general however, fraying does not appear to be as serious a problem as bark stripping. The average frequency of wounding is lower and the size of wounds are smaller than bark stripped wounds (Welch *et al* 1987). It is therefore likely to have much less significance in terms of ultimate yield. Apart from incorporating fraying wound sizes into the mean wound size when estimating yield loss, we have not explored the implications of fraying any further.

2.1 Differences between age and species

The differences between the species and age of trees needs to be considered when comparing levels of damage between forests or within a particular forest over a period of time. Inevitably this is difficult to do without information on relative susceptibilities to damage.

A number of previous investigations have reported differences in susceptibility between species. Typically, Norway spruce, Lodgepole pine, rowan and willow are regarded as very susceptible, whereas Sitka spruce, birch and silver fir usually suffer relatively minor damage. Douglas fir, larch and Scots pine are usually ranked intermediate. (Pels Rijcken 1965; Ueckermann 1956; Holloway 1968; Gill 1992a; table 2 and 3). Inevitably, there are discrepancies between authors which can make interpretation difficult. Larch for example is regarded by some as less susceptible and Douglas fir as very susceptible (Pels Rijcken 1965; Ueckermann 1956).

In view of the fact that susceptibility to bark stripping is dependent on morphological features such as bark characteristics and branch senescence, the timing of the onset, peak and decline in the rate of damage differs between species and stand growth rate. In general, pines and larches are vulnerable for younger age classes than spruce (Table 1). Several investigations have also shown that larger trees suffer more damage in the early part of the vulnerable age band and conversely, smaller trees are damaged more frequently later on (Welch *et al* 1987; Gill 1992a). Selection for girth is therefore more focussed than selection for age. However, with the exception of Welch et al (1987) there are few studies which provide damage rates in relation to girth, thus most comparisons between species and sites have to be related to age.

For logistical reasons, most studies have had to be limited to a restricted range of species and age classes. For this reason, we have re-analysed the results from an extensive survey of damage carried out between 1977 and 1981 in Galloway (see section 1.2). This survey included a large sample of trees (~120,000) and embraced a wide range of age classes for each species (Table 3). In view of the relatively low levels of fresh damage recorded, the analysis was based on trees with both ‘new and old’ damage and ‘new’ damage, but fitted different parameters to each Weibull curve. This had the advantage of making use of all the available data while reducing the number of parameters to be fitted (Figure 1a and 1c).

The results indicated that lodgepole pine received far more damage than other species (peaking at 3.4%/year at age 15) and that Sitka spruce received very low levels of damage (<0.2%/year at age 19). Furthermore, the peak age of susceptibility varied between species, with larches peaking at a younger age than the other species (Figure 1a).

Having fitted the function shown in figure 1a, it then becomes possible to calculate a cumulative damage curve for each species (Figure 1b.). This curve shows the total number of trees that would be expected to suffer damage during a crop rotation, assuming no further change in factors that affect damage (other than age) after the survey date. It is potentially the most useful derivation that can be obtained from damage surveys, because it gives the best estimate of the amount of damage that will affect yield loss. The cumulative damage was estimated at 41.5% for lodgepole pine, 11.4% for Norway spruce; 6.3% for larch and only 0.7% for Sitka spruce.

Making use of the Weibull functions for each species, it is also possible to estimate by iteration the time taken for wounds to heal, which was approximately 13 years on average for this forest. This calculation also served as a check of the fit of the model, indicating a slight tendency for ‘new’ damage to be under-recorded (Figure 1d). The estimates of the cumulative levels of damage would therefore be conservative.

2.2 Variation in levels of damage

After accounting for differences in damage that may be due to age or species differences, it is possible to make valid comparisons between sites or within years for a given site. The results of the survey for Galloway did not however reveal significant year-year differences on ‘new and old’ damage and there were too few observations of ‘new’ damage alone in each year to make meaningful comparisons. Holloway (1968) also made an analysis of year to year variation in bark damage by analysis of felled stems, however although some variation is apparent in his results, it is not clear whether the differences are statistically significant.

It is clear nonetheless that there is considerable variation in the levels of damage between forests (table 2). Welch *et al* (1988) found a peak rate of damage to Sitka spruce of about 1% per year, which implies a cumulative level of damage of around 23% (the author’s calculation of 27% does not appear to take account of repeated damage). Even higher rates of damage were reported by Scott (1998), where 9.5% of Sitka spruce trees of a 22 year old stand were damaged in one year after a fence was dismantled at Mar Lodge Estate. At this site, damage to larch and Scots pine in the same block ranged from 5.6-31.6% and 0.9-20.0% respectively, with edge trees being most affected.

Table 1. Age range of maximum vulnerability to bark stripping by red deer.

Species	Age Range of Vulnerability	Reference
Norway spruce	18-38 10-20	Holloway (1968) Girompaire and Ballon (1992)
Sitka spruce	22-32 15-28	Holloway (1968) Welch et al (1987)
Lodgepole pine	7-15+	Holloway (1968)
Scots pine	5-15 11-30 5-15 8-16	Girompaire and Ballon (1992) Holloway (1968) Pels Rijcken (1965) Lavsund (1974)
True fir	6-20	Holloway (1968)
Larch	10-28	Holloway (1968)
Douglas fir	7-15+ 5-20	Holloway (1968) Girompaire and Ballon (1992)

Table 2. Levels of bark stripping reported in damage surveys.

a) Estimates of the percentage of trees stripped per year.

Reference	Age	Species					
		SS	LP	LA	NS	DF	Fir
Mitchell & McCowan 1986	3		0.0				
Rannoch, Perthshire	5		0.43				
520ha	10	0.0	0.20				
	12	0.0	0.23				
Welch et al 1987	0-8	0.0					
Glenbranter, Argyll	9-14	0.6					
	15-28	1.0					
	29-44	0.5					
	>44	0.1					

b) Estimates of the percentage of 'new' and 'old' damage.

Reference	Age	Species					
		SS	LP	LA	NS	DF	Fir
Holloway 1968	6-10						16.3
Keillour, Perthshire	11-15		23.6	12.6		23.9	33.8
566 ha	16-20		45.6				13.2
	21-25						
	26-30	15.9					
	31-35				10.0		
	36-40						
	41-45	9.3		5.1	33.8		
	46-50						
	51-55						
	56-60				17.6		
	61-65				12.8		
	66-70				27.3		

Table 3. The percentage of trees bark stripped by red deer in Galloway 1977-81.

Figures represent the percentage of trees with both 'old' and 'new' damage in for each species and planting year class. Empty cells indicate no observations.

Spp	Survey Year	Planting Year									
		71-75	66-70	61-65	56-60	51-55	46-50	41-45	36-40	31-35	26-30
LP	**1977**	2.71	20.20	26.51	42.84	25.73			8.00		
	1979	6.12	15.31	34.35	32.57	24.93	28.88		0.00		
	1980	0.00	46.70	18.68	49.78	19.52	33.33	0.00			
	1981	2.80	33.15	24.79	26.61	17.33	0.00		0.00		
SS	**1977**	0.06	0.10	0.78	1.27	0.47	0.31	0.00	0.60	0.00	0.00
	1979	0.03	0.06	0.35	0.75	0.29	0.40	0.25	0.00	0.00	0.00
	1980	0.14	0.00	0.36	0.45	0.04	0.30	0.91	0.00	0.00	0.00
	1981	0.22	1.28	0.80	0.55	1.13	0.07		0.00	0.00	0.00
NS	**1977**	0.00		0.00	0.00	3.92	6.59	5.26	7.00	0.00	
	1979	1.73	2.38	11.16	5.00	5.37	2.00	9.00	0.23	0.00	0.00
	1980	0.00	0.00	0.00	0.23	1.24	2.67	3.89	4.67	0.00	0.00
	1981	1.20			16.00	5.32	1.23	14.00	16.45		0.00
LA	**1977**	0.00	34.9	0.40	1.69	1.64		0.00	0.00	0.00	
	1979	0.00	3.33	60.00	1.04	1.19	0.00		0.00		0.00
	1980	9.48		5.58	4.03	2.26	0.56	0.00	0.00		0.00
	1981	0.00	1.48	0.75	1.92	1.56	0.00		0.00	0.00	

Figure 1a,b and c. The probability of trees suffering bark damage as a function of age and species in Galloway, 1977-81.

A Weibull function was fitted to the proportion of trees recorded with 'new' (or 'new'and 'old') damage:

$$p_x = k[cb^c x^{c-1} e^{-(bx)^c}]$$

for x = 0,1,2… where p_x is the probability of new damage at time x and x is the age of the tree in years.

For new damage the value of the parameters obtained were as follows (figure 1a):

	k	*c*	*b*
Larch	0.065	1.67	0.058
Lodgepole pine	0.529	2.80	0.059
Norway spruce	0.124	1.64	0.036
Sitka spruce	0.007	4.00	0.050

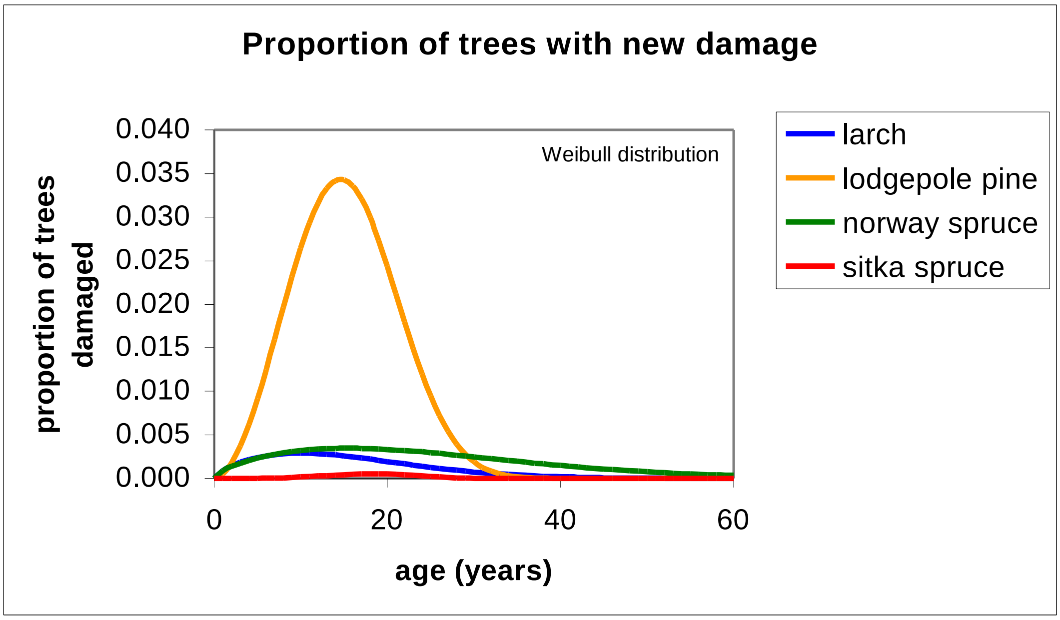
For both new and old damage (figure 1c):

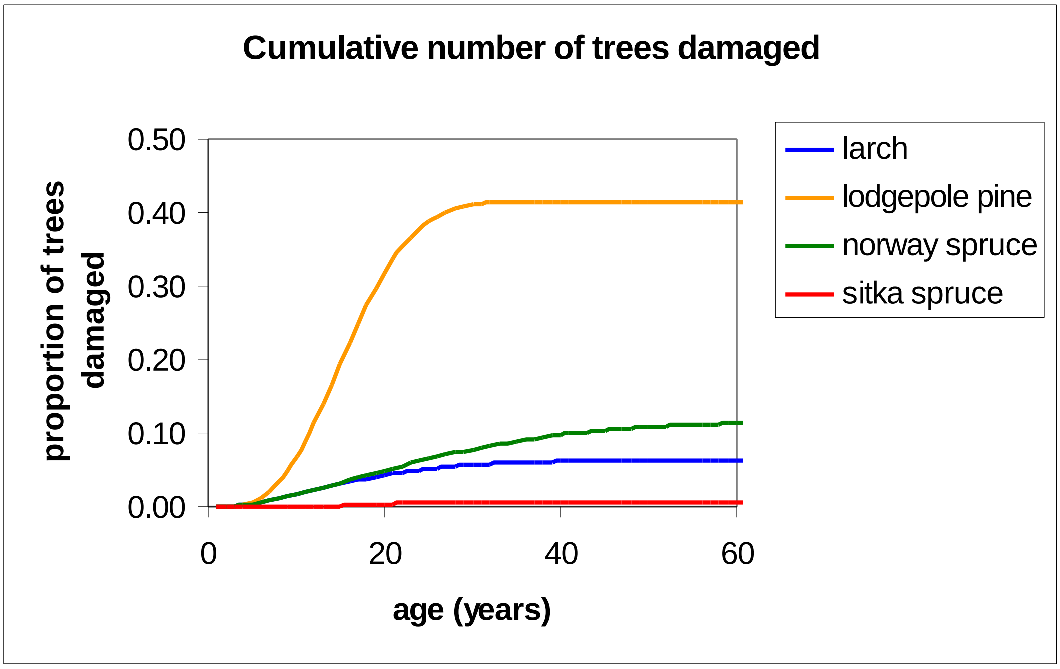
	k	*c*	*b*
Larch	0.565	2.00	0.060
Lodgepole pine	6.831	3.10	0.045
Norway spruce	2.519	2.65	0.028
Sitka spruce	0.252	2.53	0.040

Using the above equation for 'new' damage, it is then possible to estimate total cumulative damage as follows (figure 1b):

$$c_x = c_{x-1} + [p_x - (c_{x-1}.p_x)]$$

for x = 1,2,3 … where c_x is the probability of a tree being damaged at least once by time x and p_x is as above.


Proportion of trees with new damage
Weibull distribution
proportion of trees damaged
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
20
40
60
age (years)
larch
lodgepole pine
norway spruce
sitka spruce


Cumulative number of trees damaged
proportion of trees damaged
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
age (years)
larch
lodgepole pine
norway spruce
sitka spruce

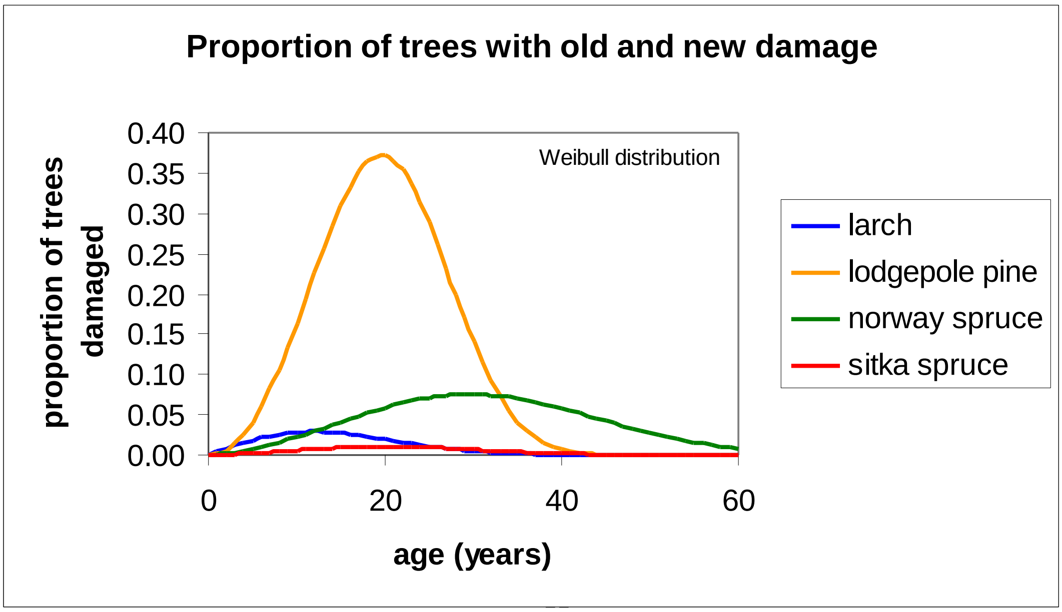
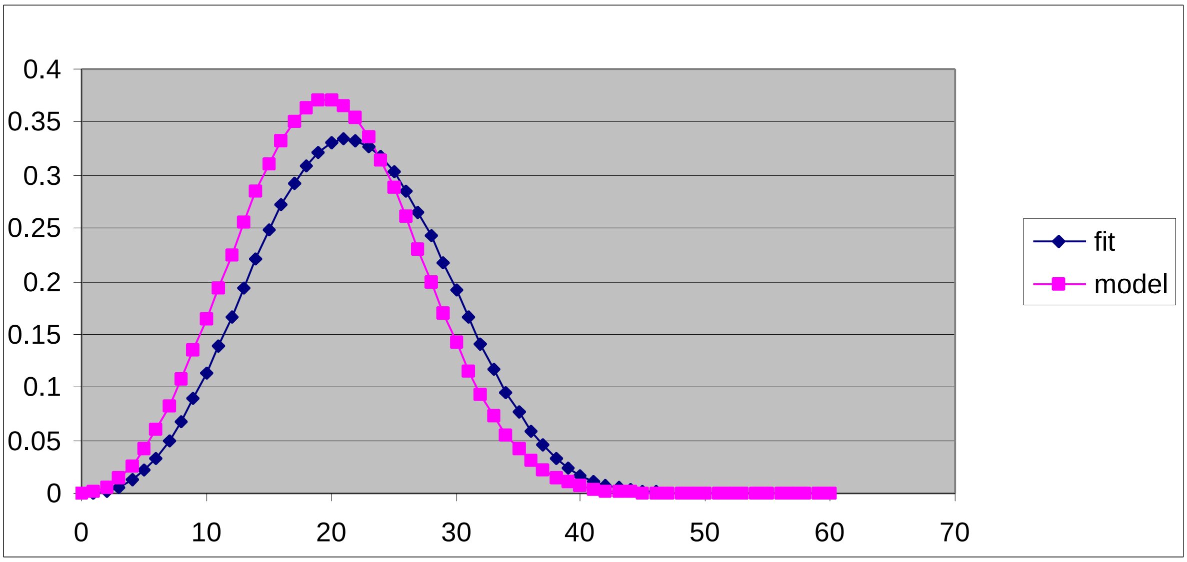

Proportion of trees with old and new damage
Weibull distribution
proportion of trees damaged
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
20
40
60
age (years)
larch
lodgepole pine
norway spruce
sitka spruce

Figure 1d. Estimated visible levels of damage obtained by comparing the model derived from observed data (pink) with an estimate obtained from the rate of new damage and a wound healing time of 13 years (blue).



2.3 Bark wounds and pathogen infection

The intact bark on standing trees is an effective barrier against invasion by wood degrading micro-organisms which consist primarily of bluestain and decay fungi.

The former, which cause sapstain or discoloration of timber, have little effect on wood properties (Seifert, 1993), whereas decay fungi not only discolour the timber but gradually destroy its structural integrity. Any damage to bark either during extraction or as a result of animal feeding, presents an opportunity for the ingress of these damaging agents. However, a number of factors influence the likelihood of fungal infection taking place: these include time of year, conifer species and probably also wound type and size.

2.3.1 ***Wound infecting agents***

Bluestain fungi tend to grow and sporulate less during winter as ambient temperatures decline, so there is relatively little inoculum available in the form of spores to infect any newly made wounds. In contrast, some decay fungi such as *Heterobasidion annosum* produce spores all through the year but, even so, spore numbers are reduced during the winter so wounds produced at this time of year are less likely to become infected. As wounds age they also change in their susceptibility to wood invading fungi; in a matter of days or weeks alterations occur in the damaged tissue that limit the process of fungal infection. The wood around a wound becomes impregnated with resin (eg Pels Rijcken) and antifungal compounds become concentrated around damaged tissue (Woodward and Pearce 1988). Several researchers have also observed that when the wood is splintered or damaged, there is a much greater likelihood of decay developing under these conditions compared with wounds where only bark damage has occurred (eg Pawsey and Gladman 1965; Isomaki and Kallio 1974).

Marked differences in susceptibility to wood degrading fungi also exist between the various commercially grown conifer species. Pines such as Scots and lodgepole, are especially susceptible to bluestain whereas Sitka spruce is not. Norway spruce is also generally acknowledged to be much more severely affected by wound staining fungi than Sitka spruce, Douglas fir or larch. Comparing trees of similar age, Pawsey and Gladman (1965) found decay established in 16% of stem wounds on Norway spruce, but in only 3% of wounds on Sitka spruce. These differences in the intrinsic susceptibility between species add to the difficulty of making any generalisations about the economic impact of deer damage to commercial forestry.

2.3.2 *Wound type*

As already indicated in Section 2.2 only rarely do bark-stripping wounds made by deer encircle the whole stem. However, the size of wounds sustained by individual trees can vary markedly, although the biggest wounds tend to be found on trees with larger girths. There is also some evidence to suggest that certain conifer species are favoured for bark stripping so, on average, may have larger wounds than less preferred species. For example Welch et al. (1988) reported that wounds on Norway spruce tended to be slightly bigger than those found on Sitka spruce. In another study, Scott (1998) observed that in a Scots pine plantation mixed with some larch and Sitka spruce, the largest deer stripping wounds occurred on the pine and larch.

Once the bark is pulled from the tree, the exposed wood tends to be quickly covered by a crust of resin and appears discoloured (see Figure 2a). Since the cambium is removed by the stripping, no further diameter growth can occur at the wound face and the wound can only be healed over by proliferation of the surrounding cambial tissue. The time needed for this to occur depends on the size of the wound and the vigour of the tree, but Han *et al.* (1999) considered that it is the width, rather than the length of a wound, that is the over-riding factor in determining the rate of closure. They found wounds up to 10 cm in width made on 30-40 year old Sitka spruce and Douglas fir, were completely occluded just 8 years later. In contrast, Girompaire and Ballon (1992) have suggested that wound closure in species such as Scots pine and Norway spruce may be much slower (>5mm/yr).

If wounds cover a sizeable proportion of the girth of the tree, then stem growth is asymmetrical at the level of the stripping wound (Figure 2b). Eventually, however, the occluding edges meet over the wound (Figure 2c), and the cambium joins up again. Sometimes bark tissue is occluded into the healed wound along with pockets of resin as well as discoloured wood. After healing has completed, the stripped place is usually visible for a time as a strip like depression and, with severe wounds, a distinct flattening may always be apparent on the stem. The internal structure of wound wood also differs from normal wood with changed density and fibre length. This may be one reason why old bark wounds are often the point of breakage during wind or snow damage.

Figure 2a

Partially healed wound, showing discolouration of sapwood and extent of callousing. The wound extended to 75% of circumference when made and was photgraphed 11 years later.

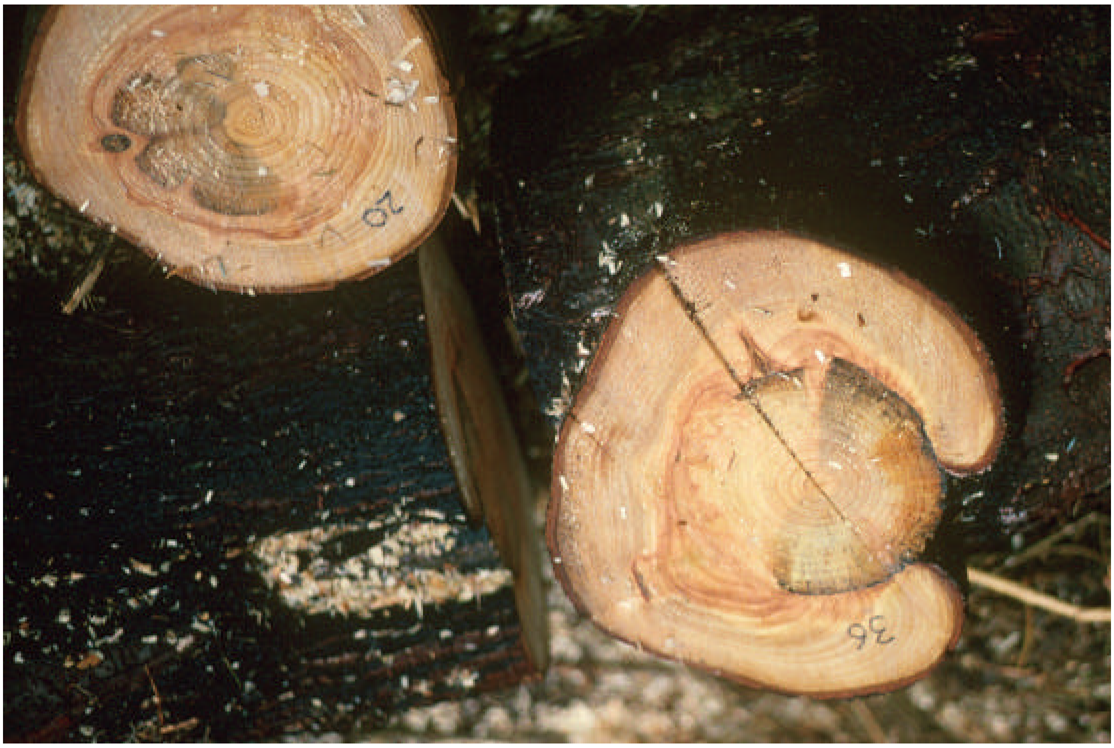


Figure 2b.

Section through a Sitka spruce stem showing assymetrical wood growth following bark stripping. Some pink-brown staining in the sapwood under the wound is also visible indicating fungal activity.

Figure 2c

Fully occluded wound 11 years after wounding which removed bark from 25% of the circumference.

Table 4. Extent of bark stripping wounds resulting from red deer damage

Species	*Age*	Range of wound sizes			*Reference*
		Length (cm)	Width (cm)	Area (cm^2)	
Ash	22-40	28-211	6-47		Vasiliauskas and Stenlid (1998)
Scots pine	5-15	23 (mean)	2 (mean)		Pels Rijcken (1965)
Scots pine	2-10	30-35			Girompaire and Ballon (1992)
Scots pine	25			<10-2275	Scott (1998)
Sitka spruce	30-40			100-450	Gregory (1984)
Sitka spruce	30-40			3-883	Gregory (1984)
Sitka spruce	20-25	12 (mean)	4(mean)		Welch et al (1988)
Norway spruce		13 (mean)	5 (mean)		Welch et al (1988)
Norway spruce				6-575	Holloway (1968)
Douglas fir	10-20	55-65			Girompaire and Ballon (1992)
Larch	25			<10-1723	Scott (1968)

2.3.3 Fungal invasion following bark stripping

Several studies have been carried out in Europe to assess the extent of fungal invasion in Norway spruce, following bark-stripping injury as a result of extraction or animal damage. More recent studies have focussed on other species such as Sitka spruce, Scots pine and Douglas fir (Gregory 1986, 1986; Girompaire and Ballon 1992). A positive relationship between wound size and the extent of fungal invasion (estimated from the amount of stained wood) has been found consistently by many of these researchers. Gregory (1986) reports that wounds exceeding 300 cm^2 were most likely to suffer serious fungal degrade, while Welch and Scott (1999) considered wounds of more than 180 cm^2 were more often associated with stain when contrasted with smaller wounds.

The stain itself has been classed into two forms: 'dark' stain likely to indicate the development of severe decay over several years, and 'light' stain which is often barely detectable and may be the response of the tree to wounding and not a sign of invasive microbial activity (Gregory 1986). The rate of stain extension has been found to range from around 2 cm a year, up to more than 30 cm a year and therefore may extend longitudinally for more than a metre beyond the area of stripped bark. Once the wound is occluded by bark there is evidence to suggest that rates of extension slow significantly. In experiments that simulated deer stripping, with controlled amounts of bark removed from 22 year old trees of Sitka spruce and lodgepole pine (see section 1.2), both types of stain were evident. Moreover, the extent of stain was clearly associated with wound severity, and the extent of the stain tended to be less in the lodgepole pine (see Figures 3a and 3b). However, it is notable that with 'real' bark stripping, many wounds do not result in any decay establishing in the wood. Wounds on Sitka spruce and larch appear to be the least susceptible, while Norway spruce is most prone to developing long columns of stain and decay (Gregory 1986; Bazzigher 1973; Pawsey and Gladman 1965). It may be that many wounds escape infection because the winter time bark stripping activity of deer also coincides with period of lowest fungal activity.

A number of fungi have been recorded from the stained sapwood, and these in the main consist of basidiomycete fungi capable of causing decay such as *Stereum sanguinolentum*, *Sistotrema brinkmanii* and *Heterobasidion annosum*. Other frequent colonisers are not decay fungi although they are capable of discoloring the wood (eg *Ophiostoma piceae*, *Nectria fuckeliana* and *Penicillium* spp.

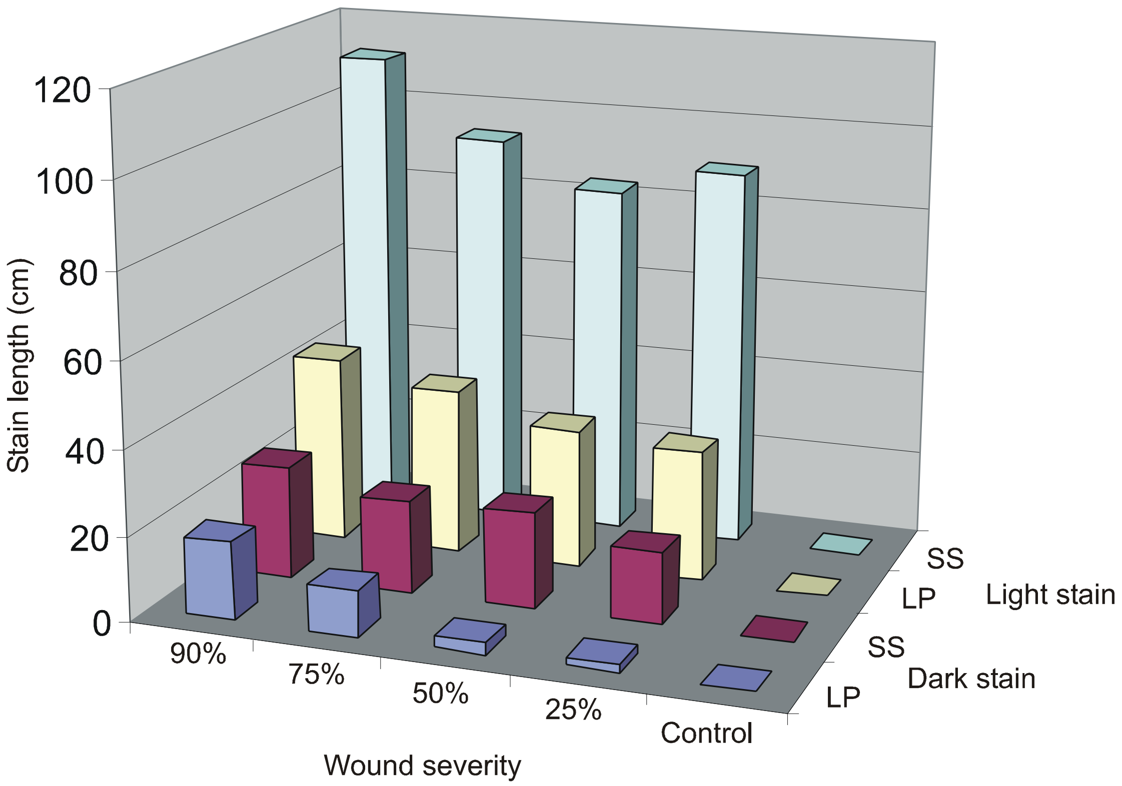


Figure 3a
The extent of light and dark stain in Sitka spruce and lodgepole pine after wounding.

Vertical bars represent the mean length of stain (cm) (both above and below the wound) obtained from a sample of 20 trees of each species and treatment class. Stain length was assessed 11 years after wounding.. Wound severity is expressed as a percentage of the initial circumference of the tree.

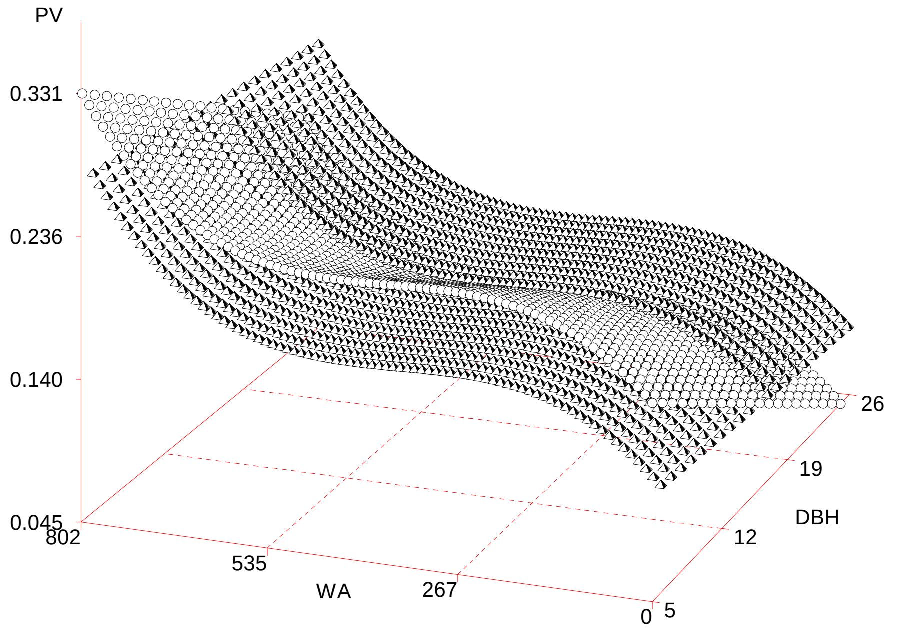


Figure 3b.

Model of timber volume degraded (expressed as proportion of total stem volume) in relation to stem dbh (cm) when wounding occurs and wound area (WA) (in cm^2). Sitka spruce is shown as open circles and Lodgepole pine as pyramids. The measure of timber volume 'degraded' used in this model was taken to be the volume of the stem between the upper and lower limits of the extent of light stain in logs 11 years after deliberate wounding (see figure 3a). Both surfaces are plotted for trees with a growth rate of 0.6cm dbh/year and a wound height of 80cm above ground. The difference in slope of each surface in relation to d.b.h. arises because lodgepole pine has more stem taper than Sitka spruce, thus a greater proportion of stem volume is affected by stain in larger girthed trees. For both species, lower growth rates and higher wound heights would yield a higher proportional loss for both species. The surfaces are described by the equations $V_{(SS)} = 0.243 + 0.000493WA - 0.00000141WA^2 + 0.0000000013WA^3 - 0.00642dbh - 0.06276inc$ and $V_{(LP)} = 0.157 + 0.000493WA - 0.00000141WA^2 + 0.0000000013WA^3 - 0.01189dbh - 0.06276inc$; $F=25.59$; 7,157df; $R^2=0.533$; $p=0.0001$.

2.4 Implications for timber quality

It has been a source of concern for many years that in addition to mortality, bark stripping and fraying has the potential to cause significant reductions in the timber quality of commercially grown conifers leading to a decrease in market value. Such damage may cause a decrease in the value both in the roundwood and in the sawn lumber once the logs have been converted at the sawmill.

Initially, the economic impact of bark stripping may be revealed when parcels of logs are inspected prior to sale. Although many growers including the Forestry Commission are increasingly turning to sales of standing timber, if saw-logs are offered for sale they are classified and described for sale as ‘Green or Red’, green being the higher quality (Anon, 1993). If saw-logs fail the criteria for red logs, they may be re-cut to shorter length or even down graded to pulp. The descriptions for red and green classes are detailed in Table 3, but down grading may occur for a variety of reasons including bow, presence of significant scars, signs of visible decay and any staining of the wood, as the latter is taken to indicate incipient decay. As bark stripping by deer can result in external scars or stained wood that is sometimes visible at the time of harvest, there is the potential for individual logs to be downgraded from green to red. The consequent loss in value is usually around £6-7 m^3, depending on the conifer species and log size. Currently, the respective values for green and red logs of spruce are around £32-35 and £25-28m^3 (under-bark), and as much as £44 and £34m^3 for pine in some areas. Logs destined for pulp only command about £20 tonne.

The effect of deer damage to sawn timber prices is more difficult to quantify, as the outcome of damage (occluded bark, resin pockets and columns of stain and discoloration in the sapwood) may not be revealed until after the logs have been processed. If the sawn timber is destined for use in the construction sector (which commands some of the highest prices for timber), then each sawn wood section (known as a batten or deal) is mechanically grade for strength according to British Standard 5268 (see Lee *et al*. 1999). However, even if the timber meets strength requirements and successfully grades to the most commonly used construction grades of C16 or C24, it will still be rejected if retains any bark or if there is any visible stain or discoloration.

In a detailed study, Welch and Scott (1999) examined the impact of bark stripping followed by fungal colonisation on the timber strength of Sitka spruce. They compared the modulus of elasticity (stiffness) and the modulus of rupture (breaking strength) of small knot-free sections of wood taken from above and below wounds. Although they did find that MoE and MoR were reduced in wood that was stained, it was largely limited to wood that not only was stained but also had visible rot present. Stain alone did not appear to reduce the strength of the wood samples. These results co-incide with those of Pratt (1979) who found that even when the decay fungus *H. annosum* could be isolated from Sitka spruce, unless the wood was visibly rotted it was not significantly different in strength from stain-free that did not contain fungus. However, the readiness to reject stained wood comes from the widespread belief in timber markets that stained wood is more susceptible to subsequent decay, although this has yet to be proven. What is clear is that stained wood is rarely compromised in terms of timber strength.

2.5 Estimates of yield loss from stain and decay

It is possible to estimate the financial loss from bark stripping by applying available estimates of rates of damage, mean wound size, height of the wound above ground and the rate of stain extension to calculations of timber yield from stands of a given age and yield class. In the examples given below, a mean wound area for bark wounds on Sitka spruce was taken as 79.2cm^2, calculated from the product of mean wound size and number of wounds per tree reported in Welch *et al* (1987; 1988). The extent of stain that would develop from wounds of this size was estimated from a regression obtained the experiment (Y14/26) on artificially damaged trees, ($s = 2.362 + 0.490w - 0.00138w^2 + 0.00000122w^3$ where s= length of light stain above the wound and w = wound area cm^2, F=35.33 3,88df r^2=0.55 p<0.0001). For a wound area of 79.2 cm^2, this equation yielded an estimate of 33.1 cm of stain above the height of the wound. The average height of wounds above the ground was taken as 80cm (Welch *et al* 1987), thus the affected length of stem is 1.13m. In view of the fact that the stain length in this experiment was not obtained at the end of rotation, a figure of 140 was also used on the assumption that stain may extend at a constant rate (2.76cm per year) for another 10 years.

The estimation of financial loss can be calculated either assuming the damaged portion of the stem is sold for pulp and the remainder remains suitable for saw-logs (table 6) or that the lower saw-log will be downgraded, from green to red and the remaining logs unaffected. In the first case, estimates of yield loss ranged from 3.8-6.8%. Since these estimates apply for a case where every tree is damaged, the product of these figures and the levels of accumulated damage suggest an overall yield loss in the region of 0.03% in for the level of damage recorded in Galloway or 1.03% in Argyll.

If wounding were to result in all logs being downgraded from red to green then the reduction in revenue may be greater, unless the length of stain were to exceed the minimum log length of 2.4m. If this length were to be removed and lowest log downgraded, the yield loss would be 8.8% or 6.6% for yield classes 12 or 16 Sitka spruce respectively, with 100% damage.

The loss of yield in some other tree species is likely to be significantly greater. Norway spruce in particular receives higher rates of damage, larger wound sizes and longer length of stain (Gregory 1986; Welch et al 1987; 1988; Gill 1992a; 1992b). More information on stain development and suitable yield models are however required before estimates of yield loss can be calculated in other species.

In most of the examples quoted for Sitka spruce, the loss of revenue was relatively lower for longer rotations or higher yield class stands. This is because the length of stain was relatively short, making removal of the lower section an attractive option. However if the length of stain extended further up the stem, then the loss of revenue may be greater for higher yielding stands or longer rotations.

Table 6. Estimates of possible yield loss from a stand damaged by bark stripping.

Estimates have been made on a per hectare basis for a stand of Sitka spruce, yield classes 12 and 16 for 45 and 60 year rotations and assuming a stump length of 0.15 (undamaged), 1.13 or 1.4m. Assortment into saw-log or pulp is made using a yield model (Forest Research 1999). The value is calculated assuming the stained stump section ('residue') can be sold as pulp @ £20 per tonne and all remaining saw-logs will be graded as 'green'. Valuations are based on the price of £32 per m^3 for saw-logs. Estimates of the loss of value are based on a case of all trees in a stand being damaged.

Yield Class	Stump length (m)	Felling Age	Sawlog vol. (m^3)	Pulp vol. (m^3)	Residue (m^3)	Value £	Loss of sawlog vol. (%)	Loss in value (%)
12	0.15	45	229	200	39	11001		
		60	428	164	56	16714		
	1.13	45	193	178	97	10509	15.7	4.5
		60	363	170	115	15814	15.2	5.4
	1.40	45	174	186	109	10250	24.0	6.8
		60	355	163	129	15713	17.1	6.0
16	0.15	45	398	180	54	16049		
		60	622	153	73	22714		
	1.13	45	332	187	113	15152	16.6	5.6
		60	559	153	135	21841	10.1	3.8
	1.40	45	325	179	127	15059	18.3	6.2
		60	547	149	152	21690	12.1	4.5

2.6 Other consequences of bark stripping

2.6.1 Effects on growth

The possible effects of bark stripping on growth were reviewed in Gill (1992b). Although a few studies have claimed a growth loss following bark removal, some of them had methodological limitations and the all of those focusing on European species (Norway spruce, Scots pine and oak) failed to demonstrate any effect. The only studies revealing a significant effect were investigations of damage by animals other than deer. No significant growth loss was detected in the Lodgepole and Sitka spruce trees deliberately wounded as part of the damage experiment (Y14/26). We have therefore assumed that growth losses following stripping are either small or insignificant and have not considered them further.

2.6.2 Direct mortality

It is well known that wounding can kill trees if bark is removed from the entire stem circumference. Deer can cause wounds of this severity (Scott 1998) but they are rare and usually associated only with high levels of damage. However, a number of other investigators have commented that mortality can result from wounds that extend round only part of the tree (Holloway 1968; Ogorlu 1995; Sakabe *et al* 1998; Parks *et al* 1998). Unfortunately not all these studies make it clear whether the eventual cause of death is due to bark stripping or suppression. Since deer select the smallest trees when damage occurs in the latter part of the vulnerable period, any mortality due to the wound can be confounded with mortality due to suppression.

The distinction between these different causes of death is evident from investigations of simulated deer damage, when wounds can be applied to trees at random. The results obtained from the FC bark stripping experiment showed that Sitka spruce is unaffected even after severe damage, although wounding caused a significant increase in mortality rates in lodgepole pine (Table 7). In both species, the majority of trees died of normal causes (suppression) except for the most severely damaged lodgepole pines. An assessment of natural bark stripping damage to lodgepole pine in Scotland revealed a mean of 11.3% (n= 2861; range 0.7-51.3% between plots) of trees with wounds exceeding 50% of stem girth. If this proportion is typical, it suggests that direct mortality is likely to occur on average in only about 1% of wounded trees.

Mortality following severe natural damage has also been recorded in both Scots pine and larch (Scott 1998). In both species, only the most severely wounded trees were affected. In comparison, Welch and Scott (1998) found no increase in mortality rates among wounded Sitka spruce in Argyll.

Table 7. Mortality rates after bark stripping.

Estimates of mortality rates obtained 11 years after deliberate wounding in Sitka Spruce and lodgepole pine. Wound severity was represented as a percentage of bark removed from the total circumference of the tree. All figures are based on a sample of 60 trees of each species and treatment class.

Species		Control	Wound severity					
			25%	50%	75%	90%	Chi-sq	P
Sitka spruce	Total mortality	0.15	0.15	0.17	0.10	0.15	1.1	Ns
Lodgepole pine	Total mortality	0.15	0.12	0.30	0.22	0.42	14.7	<0.01
	Wound breakage	0.00	0.00	0.05	0.05	0.25	36.5	<0.005

3. Browsing

3.1 Variation in levels of damage

Considerable variation in browsing damage is well known to occur, and it is not uncommon to find every tree in a plantation to be damaged if unprotected. Most damage assessments focus on leader browsing, because the loss of the leading shoot can have a relatively greater effect on growth than side-shoot browsing, and may lead to stem deformation (Ericsson *et al* 1985),

In spite of the variation in damage, there are considerable differences in susceptibility between species. Larch and Douglas fir for example are usually browsed more severely than Sitka spruce, which is in turn usually affected more than lodgepole pine (Figure 4 and 5; Melville 1980). Amongst broadleaves, birch is browsed much less frequently by roe deer than oak (Gill 1999 unpubl.). For any particular species (even a relatively unpalatable species like Sitka spruce) damage can vary from 0-100% between compartments (Figure 4; De Jong *et al* 1995). Comparisons of the levels of damage between forests have indicated that damage typically varies less between compartments within a forest than between forests, thus factors that affect damage appear to be more important at the scale of the whole forest than at the compartment (Figure 4; Neal 1997).

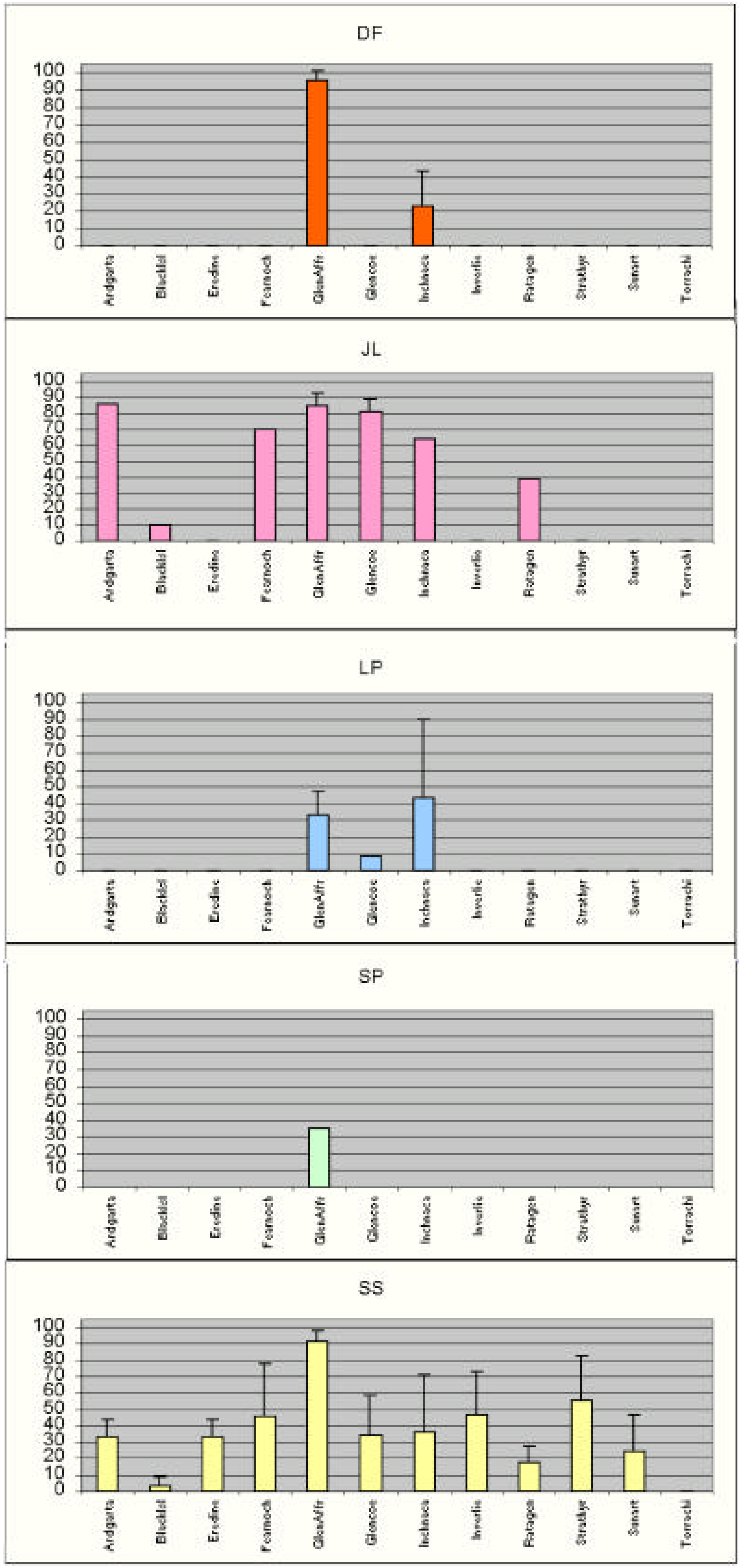


Figure 4. Mean levels of leader browsing (with 95% CI)

3.2 The effects of browsing on growth rate

In spite of a long standing awareness of the impact of deer on tree growth and stem form there are relatively few studies available which provide an estimate of the growth loss attributable to browsing. Growth comparisons are best made between protected and unprotected trees, but experiments of this kind are difficult to establish over a range of sites and to monitor throughout an entire rotation.

Welch *et al* (1992) have reported the effects of red and roe deer browsing on Sitka spruce on 15 sites and over 5-10 years in Argyll. Their results suggest that height growth is delayed by approximately one year by browsing, which equates to a 20cm height difference when trees are in the vulnerable age band, or approximately 30cm by age 5.

Differences in height and girth growth in response to roe deer browsing have been monitored in an experiment where roe deer were kept in large enclosures at various densities (Gill 1999 unpubl.). The results indicated that browsing affected some species more than others, and that height growth was reduced most in the enclosure with the highest deer densities (Figures 7 and 8). Oak, Scots pine and Douglas fir were affected more than larch, Norway spruce and alder, while birch was virtually unaffected. After 5 years, the height of the three most sensitive species at the higher deer density was on average 108-138cm less than controls. The delay in growth implied by the loss of height and girth growth may be up to 5 years (Table 8).

Estimates of the loss in height growth due to browsing are also available from an experiment where damage and growth were compared between protected and unprotected trees at 21 sites across Britain. Sitka spruce was affected less than larch and Douglas fir (Figures 5 and 6). In all cases, it was clear that repeated damage had a greater effect on height growth than a single episode of damage. The reduction in height after two years' growth for trees damaged only in the first year was 7cm (33%) for Sitka spruce, 6cm (66%) for larch and 14cm (50%) for Douglas fir. The reduction for trees damaged in two consequtive years was 13cm, 14cm and 28cm for the same three species respectively.

The use of a system of exclosures to assess browsing pressure has become widespread practice in central Europe. Estimates of growth loss from such studies suggest that beech can be approximately 80cm shorter (33%) than protected trees after 11 years (3-4 year delay) and silver fir may be 40cm shorter (70%), equivalent to a 9-13+ year delay (Roth 1996). Height losses of between 15-35cm have also been recorded for beech and 75cm for ash after 5 years in a number of other sites in central Europe (Cermak 1998). Growth of Douglas fir was found to be delayed by approximately 1.5 years (30cm or 24%) after 5 years in the NW USA (Black *et al* 1979).

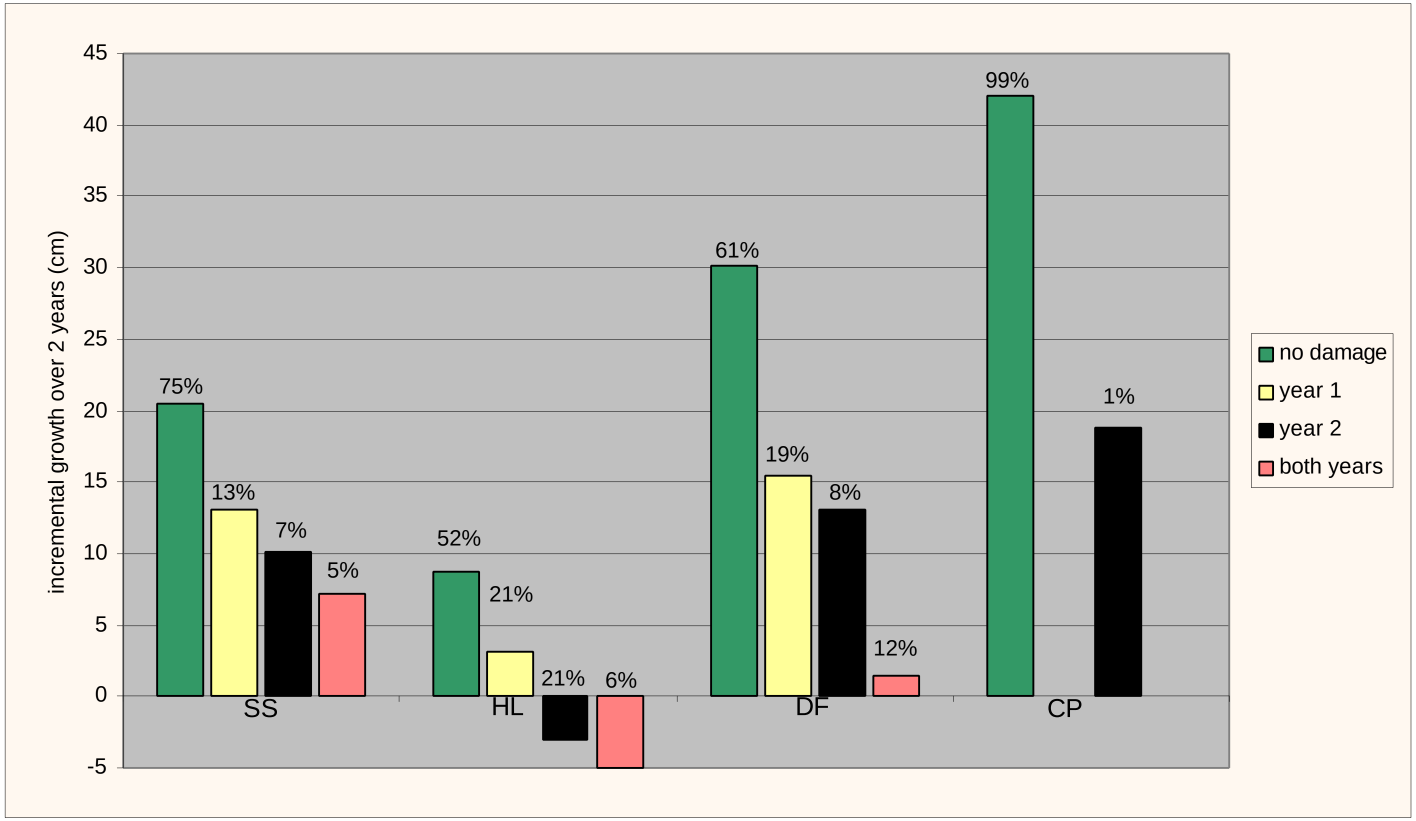
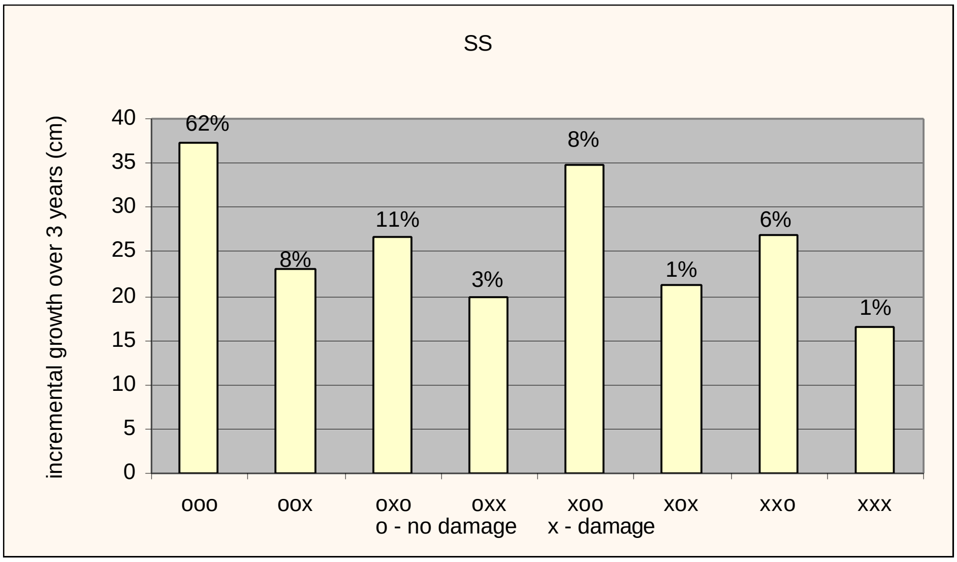


Figure 5

Incremental growth over two years in relation to the frequency of leader damage in the first and second year. The figures above the bar represents the proportion of trees of each species in each damage category.



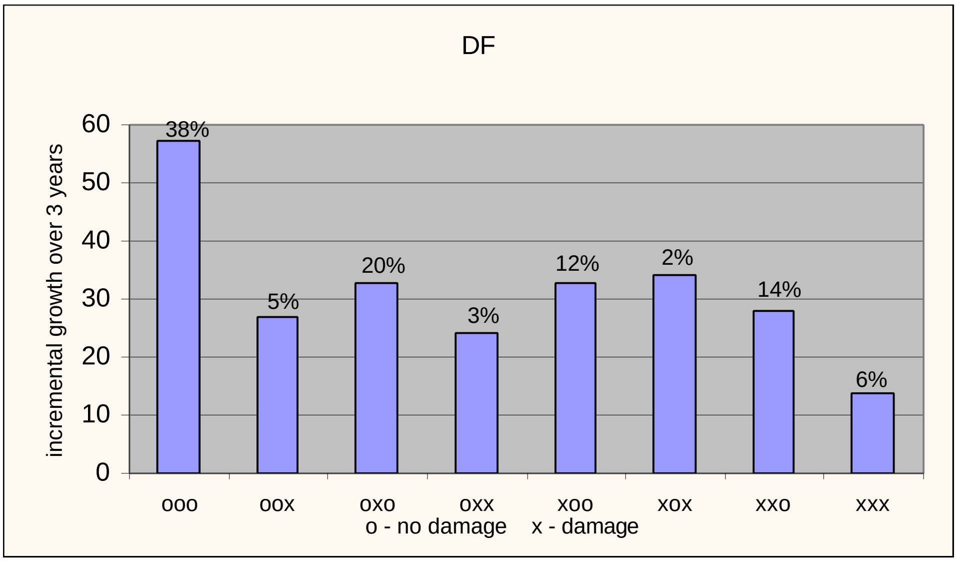


Figure 6

Incremental height growth over three years in relation to the frequency of leader damage in Sitka spruce and Douglas fir. Damage in each year is represented by the letter x below each bar. The figures above each bar indicate the proportion of trees filing into each category.

Figure 7
The effect of roe deer browsing on height and girth growth in broadleaves up to 5 years of age.

Solid dots: enclosure without deer; Open circles: Deer at medium density; Open triangles: Deer at high density.
Red: Alder; Blue : Birch; Green: Oak.
Heights are measured in cm. and girth is circumference of the root collar in mm.
Differences in height and girth were significant in oak ($p<0.02$), but not in alder or birch.

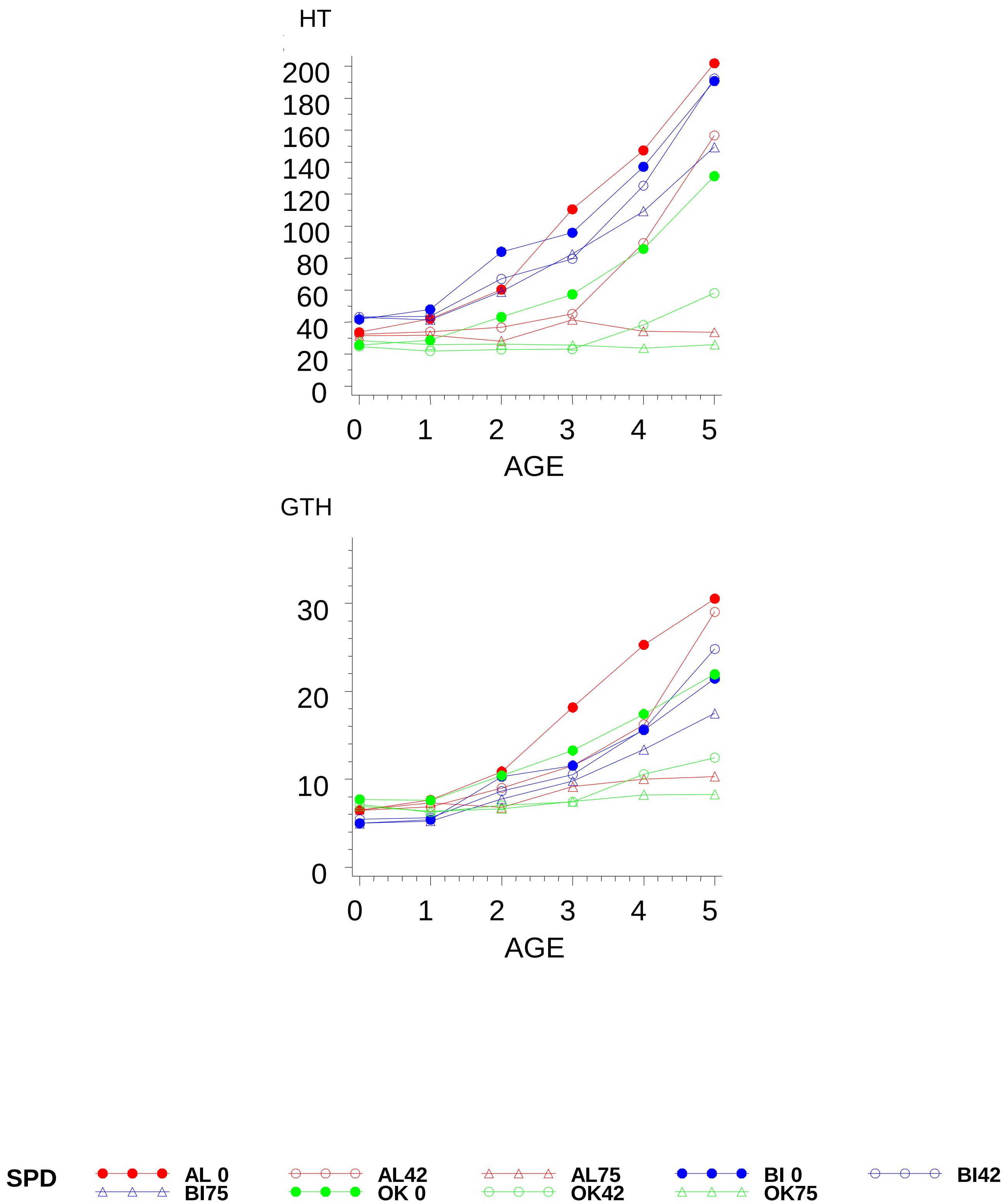
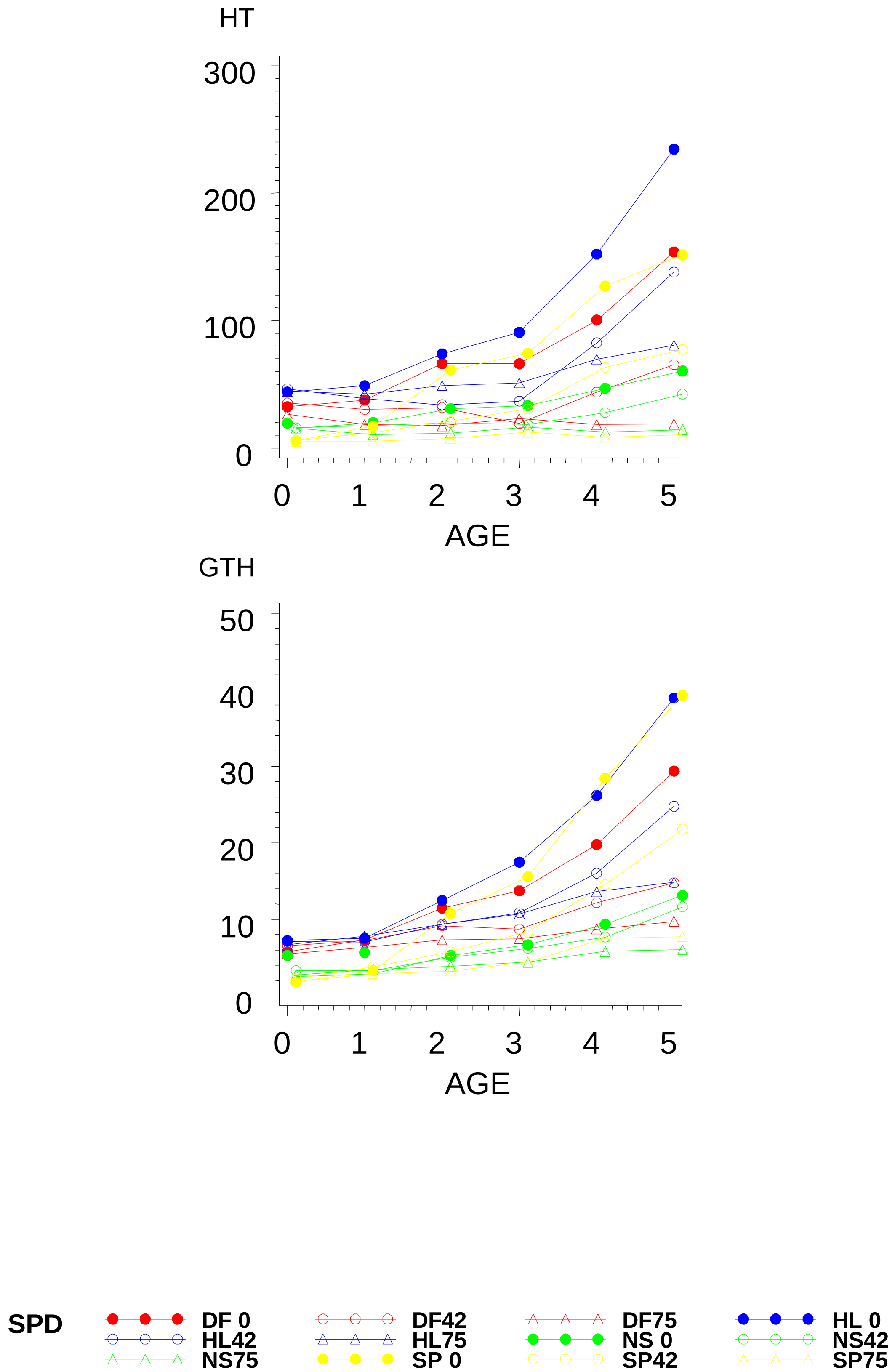


Figure 8
The effect of roe deer browsing on height and girth growth of conifers up to 5 years of age .

Solid dots: Enclosure without deer; Open circles: Deer at medium density; Triangles: Deer at high density.
Red: Douglas Fir; Blue: hybrid larch; Green Norway spruce; Yellow: Scots pine.
Heights are measured in cm. and girth is the circumference of the root collar in mm.
Differences in height and girth were significant for each species ($p<0.05$).



Interpretation of the long-term effect of browsing on yield is hampered by the lack of direct information on the degree of compensating growth that may occur after browsing. Compensation refers to an increased relative growth rate after browsing and may arise in individual trees or between trees in a stand. Compensating growth has been reported in a number of studies of browsing (Mitscherlich and Weise 1982; Kampmann 1983 in Norway spruce; Welch *et al* 1992 in Sitka spruce). However these have been relatively short-term studies and there is no data directly relating growth loss from browsing to ultimate yield.

3.3 Effects of delayed growth on yield reduction

There have been very attempts at estimating final yield losses due to browsing. Mitchell (1964) used a stem sectioning technique to assess the effects of leader browsing on height growth in Douglas fir. In this case, growth was delayed by up to two years and yield loss estimated from this to be about $15m^3$/ha by the end of an 80 year rotation, a figure slightly higher than one year's mean annual increment. In the absence of direct data, yield losses from browsing have to be estimated assuming that a delay in harvest date will be less than the delay in establishment, on the assumption that at least some compensation will occur (Table 8 and 9).

Table 8. Implied delay (years) in growth due to browsing.

Estimates of the delay in height growth following establishment, (five years after planting), based on comparisons between browsed trees and protected controls.

	Medium deer density		High deer density	
	Height	Girth	Height	Girth
Douglas Fir	2	2	5+	4
Hybrid larch	1	1	3	3
Norway spruce	1	0	4	3
Scots pine	2	1	4	3
Oak	2	2	4	4
Birch	0	0	0	0
Alder	0	0	0	0

Table 9. Estimates of the possible financial loss as a result of a delay in growth.

Estimates are based on the yield of one hectare of Sitka spruce at 2m spacing on a 'no thinning' regime. The assortment into saw log and pulp volume is obtained from the FC yield model (Forest Research 1999). Value is estimated from current timber prices (£32/m^3 for 'green' saw logs and £20 per ton for pulp). Loss is calculated on the assumption that browsing will effectively reduce the trees to their size up to one to four years previously.

Yield Class	Felling Age (years)	MAI (m^3/yr)	Vol (m^3)	Saw log vol.	Pulp vol.	Value £	Reduction in yield loss		
							1 year	2 years	4 years
12	45	10.4	468	229	200	11001	3.4%	7.2%	16.0%
16	45	14.0	632	398	180	16049	3.4%	8.0%	13.7%

3.4 The effects of browsing on survival

The impact of browsing on tree survival is less clear than the effect on tree growth. Many investigations of deer browsing have compared the density of naturally regenerated seedlings between fenced and un-fenced plots, sometimes revealing differences of several orders of magnitude. However, this approach contrasts the effect of deer on the vegetation as a whole, not solely the consequences of damage to the tree. In addition, it excludes the effects of other mammals. Where the fate of individual trees has been monitored, survival is usually only affected in trees that are small and less than a year old, or those that are very severely damaged (Gill 1992b). In many cases, browsing has no significant effect on survival. Out of the eight species planted to monitor performance under roe deer browsing pressure (Gill 1999 unpubl.), only oak revealed a significant relationship between mortality (up to age 5) and both browsing damage and increasing deer density. Survival was lowest in the high density enclosure in only four of the eight species, but for three of these (Douglas fir, Norway spruce and Scots pine), the survival rate was highest in the enclosure with intermediate deer density (Table 10).

In Scotland, Welch *et al* (1992) noted that the survival rate of planted Sitka Spruce trees was approximately 10% lower *inside* enclosures, apparently due to the effects of enhanced vegetation growth inside the enclosures. In contrast, a major investigation of damage to Douglas fir revealed that the survival rate *outside* enclosures was 14% lower when averaged over 165 sites in the NW USA (Black *et al* 1979). In this case however, small mammals were thought to cause more mortality, and caused more damage when the trees were youngest. The damage inflicted by small mammals or competition with other plants may therefore have more effect on survival than browsing by deer. However since some plant species (grasses, bracken) are tolerant or unpalatable and can increase under deer feeding pressure, young trees may be adversely affected by competition at both very low or high browsing pressure. By reducing height growth, browsing can increase the chance that young trees will be outgrown and killed by competing vegetation.

Surveys of stocking density are carried out regularly by Forest Enterprise, typically between 2 and 4 years after planting. These have revealed a consistent tendency towards under-stocking in Sitka spruce and to some extent in other species. Densities on planted sites are between 70 and 95% of the target density of 2250 Sitka spruce/ha in Scotland. This is in spite of the fact that beating up had already been done on 53.5% of the sites (Wright 1997; Smith *et al* 1998). The primary reason for the understocking was attributed to browsing in only 5.4% of sites planted in 1995 and 27.7% in 1994. However, these surveys did not differentiate between mammal species, nor sites with or without deer fencing.

It still remains unclear what proportion of mortality can be attributed to deer browsing, either directly or indirectly through the influence they have on vegetation. Most mortality of planted trees is usually attributed to shortcomings in silvicultural methods or site characteristics (Smith *et al* 1998), although this is unlikely to be the case with natural regeneration.

Table 10. Differences in the proportion of trees surviving to 5 years of age.

Estimates were obtained in enclosures containing roe deer at different densities. An asterix indicates a significant difference in survival between densities.

	Control	Medium	High
Alder	47.9	36.7	50.0
Ash	68.1	64.0	82.3 *
Birch	97.2	94.7	88.9
Oak	92.0	85.9	67.4 **
Douglas Fir	49.7	77.1	43.0 *
Hybrid larch	72.0	85.1	77.4
Norway spruce	61.0	94.2	68.7 **
Scots pine	88.6	91.5	42.5 **

Table 11. Estimated beating up costs.

Costs are calculated on the basis of £0.10 per tree and £15 per 100 trees for labour (£25 /100 trees in total) for a stand to be beaten up to 2000 trees per hectare. Costs may be approximately two times higher if weeding is also needed. Yield is calculated using the same timber prices as table 6,9 and 12.

Yield Class	Rotation length R (years)	Discounting factor (1.03^R)	Yield, £ for an undamaged stand	Loss (as a percent of yield) for a given percentage mortality		
				10%	25%	50%
12	45	3.78	11001	1.7	4.3	8.6
	60	5.89	16714	1.8	4.4	8.8
16	45	3.78	16049	1.2	2.9	5.9
	60	5.89	22714	1.3	3.2	6.5

3.5 The effects of browsing on stem form

Leader browsing can lead to the development of a fork with two or more stems in place of a single main stem. Not only does this yield thinner stems which will have proportionately lower value, but the stems may retain a bend or deformity near the fork, or a structural weakness which will result in break during a storm. As the tree grows, one of the stems becomes dominant, and the tree may become single trunked again. The stem may however remain smaller than a single-trunked tree and retain some deformity.

Stem deformities arising from deer browsing have been monitored in Sitka spruce stands of a range of ages in Argyll (Welch *et al* 1992; Welch *et al* 1995). The results indicated that approximately a third (34.7%) of stems that had multi-leaders subsequently developed multiple stems. By the time the stands were 10 years of age, between 16-52% of the stems that had been browsed by deer (but not received any other form of damage) developed a multiple stem. From about 15-20 years of age the number of multiple stems declined, from a mean of 40% at about 19 years of age to 17% at age 60. This represents a rate of loss of approximately 0.54% per year. Although some multi-stemmed trees died, mortality rates were no higher than with single-stemmed trees and most of the dissappearance was due to one of the stems becoming dominant.

As yet, there is very little data on the size and relative volumes of multi-stemmed trees in comparison with similar aged single stemmed trees. Assessments of the yield loss caused by forking is the subject of continuing research by the FC Research Agency and ITE. Data on the relative volumes of forked and un-forked trees was however obtained from a sample 35-year old lodgepole pine which were felled and measured as part of another experiment on damage. The sample included 10 forked trees with measurable timber in both stems (at least 3m length with a girth of 7cm top diameter) and 75 unforked trees . The volume of the main stem of forked trees was 11% smaller than un-forked trees for all sizes ($V_{(m^3)} = -0.1525 - 0.0162f + 0.0166dbh_{(cm)}$; F=327.5; 2,84df; r^2=88.9; p<0.0001; fork = p<0.1; f in the formular signifies forking and has a value of 0 or 1). The smaller stems contained a mean of 15.2% of total volume (range 0.7-30.3%) and none achieved the threshold 14cm diameter for use as sawlog. In terms of height, forked trees were no smaller than un-forked trees and the *total* volume of forked trees was only less than unforked trees if the dbh was less than 20cm. Larger trees had relatively greater volume for their girth ($V_{(m^3)} = -0.1489 - 0.0906f + [0.0164 + 0.0049f] * dbh_{(cm)}$; F=249.6; 3,84df; r^2=90.2; p<0.0001; fork p<0.1; fork*dbh p <0.05).

Given that there appears to be a gradual reduction in the number of multiple stems with age, it is likely that the majority of forked trees will have one stem substantially larger than the other by felling age. Unless the crop has a very low yield or a significant proportion of the forked trees have a bent stem, the majority of forked trees will be expected to have a main stem of saw log size. However the estimation of financial yield loss is sensitive to the relative sizes of the stems at the time of felling (Table 12) and more data on the distribution of sizes of forked trees would make estimates of yield loss more accurate.

Table 12. Estimates of the loss of yield that may arise from forked stems.

The estimates have been based on an unthinned stand of Sitka spruce, yield classes 12 and 16. Volumes and values are estimated per hectare. Estimates of assortment volumes were made using the Forestry Research Yield Model (Forest Research 1999).

a) Yield class 12.

	45 year rotation with 25% stems forked				60 year rotation with 17% stems forked.			
	Saw log Vol. m^3	Pulp Vol m^3	Value, £ *	Value (£) lost	Saw log Vol. m^3	Pulp Vol m^3	Value, £ *	Value (£) lost %.
Undamaged stand	229	200	11001		428	164	16714	
Damaged stand, assuming largest main stem of forked trees 15% smaller	218	211	10850	1.4%	417	175	16567	0.9%
Damaged stand, assuming largest main stem of forked trees 30% smaller	212	217	10773	2.1%	404	188	16387	2.0%
All forked stems failing to be suitable for sawlogs	172	257	10233	7.1%	355	237	15724	5.9%

b) Yield class 16.

	45 year rotation with 25% stems forked				60 year rotation with 17% stems forked.			
	Saw log Vol. m^3	Pulp Vol m^3	Value, £ *	Value (£) lost	Saw log Vol. m^3	Pulp Vol m^3	Value, £ *	Value (£) lost %.
Undamaged stand	398	180	16049		622	153	22714	
Damaged stand, assuming largest main stem of forked trees 15% smaller	381	197	15815	1.5%	609	166	22534	0.8%
Damaged stand, assuming largest main stem of forked trees 30% smaller	359	219	15514	3.3%	596	179	22360	1.6%
All forked stems failing to be suitable for sawlogs	299	279	14696	8.4%	516	258	21276	6.3%

* Value is calculated on average current (2000) timber prices in Scotland, £32.00 per m3 for 'green' Sawlogs and £20.00 per tonne for pulpwood. The density of Sitka spruce is assumed to be 0.92 tonnes per cubic metre.

4. Conclusions

4.1 The sensitivity of estimates of revenue loss

In compiling the information for this report, it became clear that there are many factors that can influence estimates of revenue loss from deer damage and the figures need to be interpreted with care.

• Estimates of bark stripping losses are sensitive to the estimate of the length of stain and decay in damaged stems. There is still some uncertainty about the rate of stain extension and the degree to which it is influenced by wound healing amongst other factors. Further, estimates have been based mean wound sizes and stain extension. No account has been made of the distribution of wound sizes and their correlation with stem size, nor possible variation in the rate of stain extension with growth rate.

• In some cases, there were indications that forest conditions and management decisions could affect the significance of damage. For bark-stripping and multi-leadering, there was a tendency for the relative importance of damage to decline with increasing rotation length or increasing yield class. This is because older and faster-growing crops produce a larger proportion of saw-log timber. However, this trend is likely to be sensitive to product allocation and the interactions between revenue loss and growth rate or felling age need to be explored in more detail.

• The effect of thinning has not been considered. Early attempts at reducing damage by selective thinning have not been successful (Pels Rijcken 1965), largely because damage is often aggregated or obscured by wound healing. However it is likely that any form of thinning will have some effect on yield loss, by altering product allocation.

• The estimation of yield loss following stripping is based on the assumption that the stained and degraded section of log could be detected and treated accordingly. However, in practice, many of the wounds would have healed over and the stained section is invisible. This could result in sub-optimal product choice, making the cost of damage in practice more severe.

• There is a lack of information on the degree of compensating growth following browsing. Until this becomes available, estimates of the growth loss due to browsing must be regarded as speculative.

• The amount of mortality following browsing requires further investigation. Because replanting costs have to be discounted, the cost of this form of damage increases sharply with the number of trees lost. However, the interaction between mortality and vegetation growth implies that that low browsing pressures can be beneficial, and there may be some advantage in adapting weeding or site preparation treatments to ameliorate the effects of browsing.

• Estimates of loss for all forms of damage are sensitive to fluctuations in timber prices and the differences in price between products.

• Estimates of the rates of damage were obtained from areas where red and roe deer occur or roe deer alone. None are obtained from areas used largely by sika deer. It is possible that sika deer inflict higher rates of damage than the two native species in certain habitat types.

4.2 Differences between tree species

In all forms of damage, it is clear that there are substantial differences between tree species in the impact of damage. Sitka spruce is a resilient species, attracting low rates of both bark stripping and browsing and developing relatively little stain after stripping. Although lodgepole pine is clearly very susceptible, it is of low commercial importance and is planted less frequently now (Table 14). Trends in the species planted in Scotland indicate that Scots pine and various broadleaved species are increasing. With the exception of birch, these species will require more deer control and in some cases also protection to get them established.

Table 14 Composition of forest in Scotland, by species and planting year class.

Figures indicate the percentage of the total area of category 1 forest within each planting year class. The last row gives the total area in km^2. Category 1 forest is defined as stands which contain or could produce saw log timber.

	91-95	**81-90**	**71-80**	**61-70**	**51-60**	**41-50**	**31-40**	**Total**
Scots Pine	9.0	3.7	3.9	14.7	28.7	34.8	37.6	14.2
Lodgepole pine	6.5	12.4	15.3	13.7	7.2	1.0	0.6	11.0
Sitka spruce	68.5	73.5	72.5	56.2	31.7	25.6	16.2	56.1
Norway Spruce	1.0	0.7	1.5	4.8	7.2	11.9	10.2	3.6
Larch	3.8	4.9	3.7	5.6	14.3	12.8	14.9	6.7
Douglas Fir	1.4	1.2	0.4	0.9	2.2	1.6	1.7	1.2
Other Conifers	0.5	0.9	0.8	1.2	2.8	2.1	4.6	1.5
Birch	0.9	0.9	0.9	1.4	2.5	4.1	4.0	1.6
Oak	1.0	0.3	0.0	0.1	0.1	0.3	1.6	0.8
Other BL	7.2	1.6	0.9	1.5	3.2	5.9	8.7	3.4
Total area (km^2)	**420**	**2085**	**2198**	**1965**	**1314**	**445**	**186**	**9092**

4.3 Comparisons between the cost of deer damage, tree protection and deer control.

Estimates of the cost of deer damage are most useful when compared to the cost of deer control or fencing. Although fencing costs vary in relation to the shape and size of the area concerned, after discounting it is likely to represent between 10-30+% of the revenue currently expected from YC12 Sitka spruce (Table 13.). As a result, it is unlikely to be worthwhile resorting to fencing unless damage is expected to be severe. Since fencing does not normally last for much more than 15 years, it is only rarely used to protect against bark stripping. On the basis of costs estimated for browsing, damage would have to be severe enough to impose a delay of the order of 4 years in addition to substantial loss from multi-leadering and beating up to justify an investment approaching 30% of revenue.

Estimates for the costs of deer control have only available for the year 1991-92. In this year, Forest Enterprise spent approximately £2.03m on rangers and their equipment; equivalent to approximately £2.30 per ha of forest. On the basis that approximately 60% of rangers' time is spent on deer control, this equates to £117 per ha of re-stock forest per year or £1.22m in total. However income from venison sales amounted to £1.26m in the same year. Thus the cost of deer control is largely offset by revenue earned, resulting in a benefit in terms of reduced damage at very little cost.

Table 13. Estimates of the cost of fencing.

Estimates are based on fencing either a 10 or 100ha square block at £7 per metre. Costs are discounted for 45 or 60 years and expressed as a percentage of the revenue expected from an un-thinned stand of yield class 12 Sitka spruce.

Area fenced	Fence length	Cost £ /ha	Cost/ha discounted for 45 yr rotation	Cost as a percentage of revenue	Cost/ha discounted for 60 yr rotation	Cost as a percentage of revenue
10ha	1265m	885	3347	30.4	5212	31.2
100ha	4000m	280	1058	9.6	1649	9.9

4.4 Further research needs

There are a number of aspects that emerge from this review that serve to highlight areas where further research would strengthen estimates of the economic significance of damage.

- More evidence is needed on the long-term effects of browsing on growth delay and yield loss. This is one area where the impact of damage is most speculative.

- Further investigation of the impact of browsing on survival and the interaction with competing vegetation. This is needed for both planted and naturally regenerated trees.

- More information on the influence of multi-leaders and other stem deformations on the size and quality of logs.

- Evidence for the relationship between rate of browsing damage and subsequent growth. This will aid assessment of the possible economic implications of various forms of damage early in the rotation.

- More information on the rate of stain advance with age following bark stripping. Although estimates of the length of stain are available, evidence for variation in the rate of advance and it's relationship with wound healing is still sparse, both in Sitka spruce and other species..

- The development of an expert system to assess the economic implications of various levels and forms of damage and to guide forest management and harvesting decisions.

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