A STUDY OF BARK-STRIPPING BY GREY SQUIRRELS IN DALMENY ESTATE (CENTRAL SCOTLAND)

by

Giannis S. Petamedes

Ministry of Agriculture,
Wildlife Management Section,
3-5 Hippocratous Street,
Athens, Greece

A thesis submitted for the degree of Master of Philosophy at Edinburgh University,

April, 1983

TO MY MOTHER

DECLARATION

I hereby declare that this thesis has been composed by myself and that the work presented in it is my own unless otherwise stated.

Giannis S. Petamedes

ACKNOWLEDGEMENTS

Firstly, my deep thanks go to the Greek State for its financial support, without which this project could not have been undertaken.

Secondly, I would like to express my sincere gratitude to Dr. J. R. Taylor for his untiring assistance, understanding my difficulties, patient supervision and guidance during the study and for his advice and criticism during the preparation of the drafts.

I am extremely indebted to Mrs. Jean Taylor for all those hours spent criticising the manuscript and for all her generosity and hospitality.

My special thanks are also due to Professor C. J. Taylor and Dr. W. E. S. Mutch for all their support and encouragement when I first arrived.

My thanks also go to my friends and to all the technical staff of the Department for their assistance during the various stages of my study and in particular to Mr. J. Landless and Mr. J. Wilson.

I would also like to thank very much Mrs. Margaret Jackson for "a job well done" in typing this thesis.

Observations were made in 1979 and 1980 in the Dalmeny Estate by the kind permission of the Earl of Rosebery. I am grateful to Mr. N. J. Findlay, Factor of the Estate for all the arrangements and the time spent with me. I would also like to thank Mr. J. Oliver gamekeeper for his kindness, help, advice and assistance which were so freely given to me.

I sincerely thank Miss J. Rowe of the Wildlife Branch of the Forestry Commission Research Station in Alice Holt, Surrey, who provided valuable information and references during the initial stages of this project.

It is with great pleasure that I thank Mr. and Mrs. Goulandris, founders of "The Goulandris' Natural History Museum" in Athens, who have greatly influenced my love towards wildlife and who counselled me to initiate this study.

Finally, my special thanks are due to my lovely wife who spent her holiday time in my study area, provided an enthusiastic second pair of eyes and hands during the most critical stages of the field work and whose patience and love were a constant source of encouragement and moral support.

TABLE OF CONTENTS

ABSTRACT

Bark-stripping by grey squirrels of some broadleaved species is regarded as a serious and as yet unsolved problem. This study was carried out to examine in depth the nature, incidence and severity of bark-stripping by grey squirrels of pole stage stands of deciduous trees in Dalmeny Estate, Central Scotland.

Beech and Sycamore were the species most severely affected. Injuries to beech started in early May and ceased after early August. Larger wounds (>10 sq. cm.) to beech peaked in late June and early July. Injuries to sycamore started in late May, ended in early August and peaked in early July.

Dominant and codominant trees were more often damaged than sub-dominants and suppressed individuals. Most of the injuries to both beech and sycamore occurred at the butt but sycamore received a greater incidence of stem injuries than did beech. In beech and sycamore a high percentage of injuries started on callus tissue of previous wounds (beech 86.6 %; sycamore 89.6 %).

The dimensions of the wounds are described.

The timing of bark stripping was related to the timing of flushing of the trees. Beech flushed earlier and was attacked earlier than sycamore.

The reasons for bark stripping are considered and suggestions for management and further research are made.

NOTATION

dbh = diameter at breast height

S = Sycamore

B = Beech

A = Ash

O = Oak

C = Conifers

H = Horse chestnut

L = Lime

Bi = Birch

E = Elm

Ac = Norway maple

a = Alder

ha = hectares

√ = check symbol

sq. cm = square centimetres

I N T R O D U C T I O N

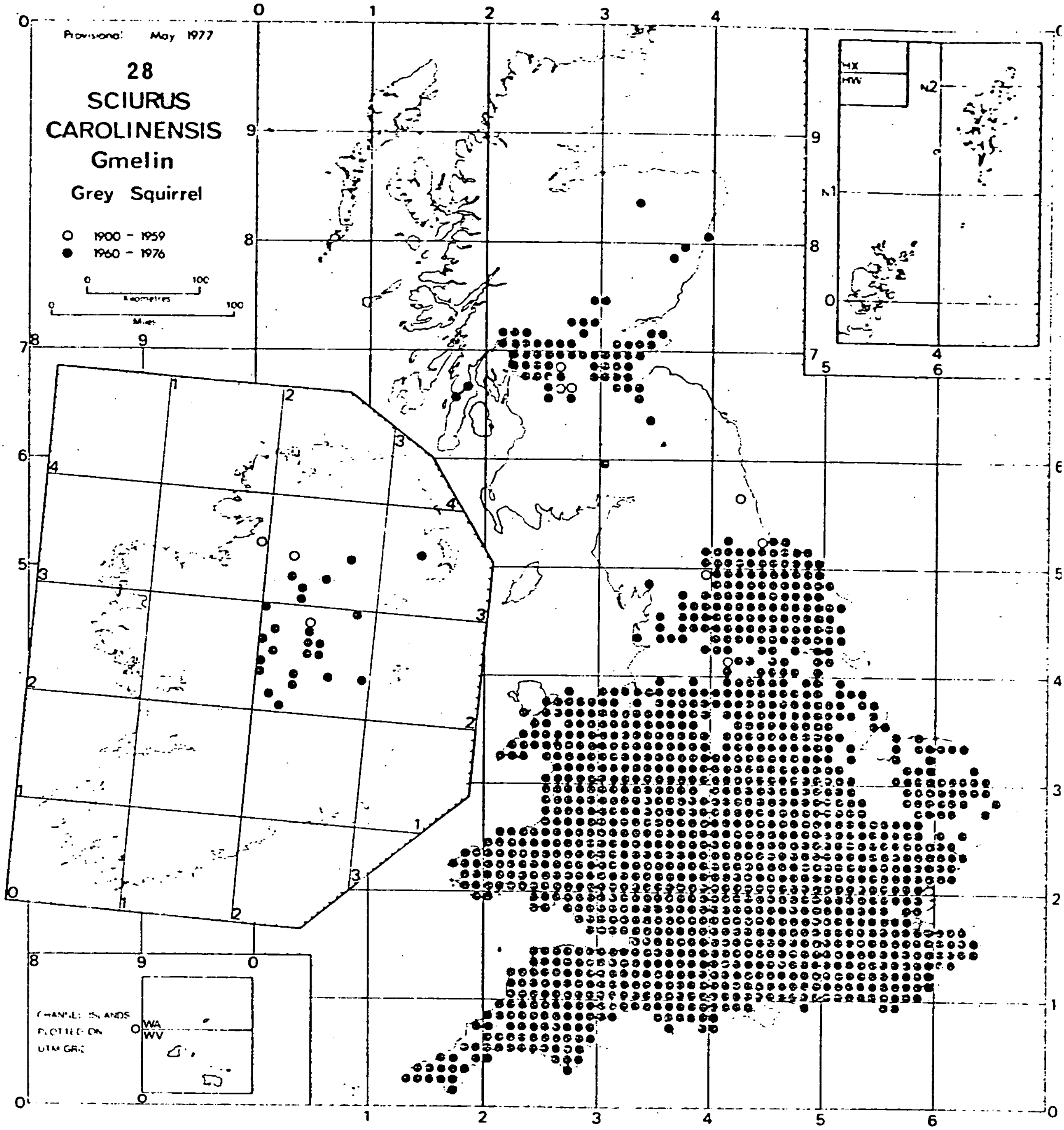
1.1 The history of the grey squirrel in Britain

The name squirrel comes from the medieval Norman "esquirel" (modern French e´cereuit), which is derived from a diminutive form of Latin sciurus, which in turn was borrowed from ancient Greek skiouros, generally interpreted as meaning "shade tail".

The Sciuridae is one of the larger families of rodents with about 50 genera and over 200 species, inhabiting all continents except Australia. The grey squirrel (*Sciurus carolinensis* Gmelin) originates in the U.S.A. The species was first introduced to Britain as a parkland amenity and released at several places between 1876 and 1929 (Middleton 1930, 1931). The introduced animals probably came from New York State and most closely resemble the subspecies *S. carolinensis leucotis* (Shorten, 1951). Releases into Scotland took place at Finnart, Loch Long in 1892, at Corstorphine in 1913 and at Dunfermline in 1919 (Shorten, 1954).

Of 33 known introductions in Britain, only one failed to become established. The most rapid spread in England and Wales occurred during the 1920's, with temporary checks in 1924 and 1930 probably because of epidemic disease. By 1930 the grey squirrel had spread over an area of some 10,000 square miles and by 1937 to 21,120 square miles (Shorten, 1954). By 1950 the different centres were coalescing and by 1975 its presence had been recorded throughout England and Wales, except north Norfolk, the Lake District, Northumberland and north Durham (Tittensor, 1975). The most recent information about its distribution is given in figure 1 (Mammal Society, 1978).

FIGURE 1 : The distribution of the grey squirrel in Britain



Source : Provisional Atlas of the mammals of the British Isles.

(Mammal Society, 1978).

The Scottish grey squirrel population has remained separate and mainly confined to the central Lowlands, with a slow spread into Peeblesshire and the upper Tay valley (Tittensor, 1975). A recent survey in 1979 carried out by the Scottish Woodland Owners Association (S.W.O.A.) revealed that the grey squirrel range is still expanding in Central Scotland (figure 2).

The main habitat of the grey squirrel is mature broadleaf or mixed forest. The native red squirrel (*Sciurus vulgaris leucotis* Kerr), has large areas of mature coniferous forest as an optimum habitat, while the invader can flourish even in small hardwood copses (Tittensor, 1975). The grey squirrel is also found in areas of scattered trees such as hedgerows, urban parks and gardens. The spread of the grey squirrel and decline of the red has been well documented by Tittensor (1975).

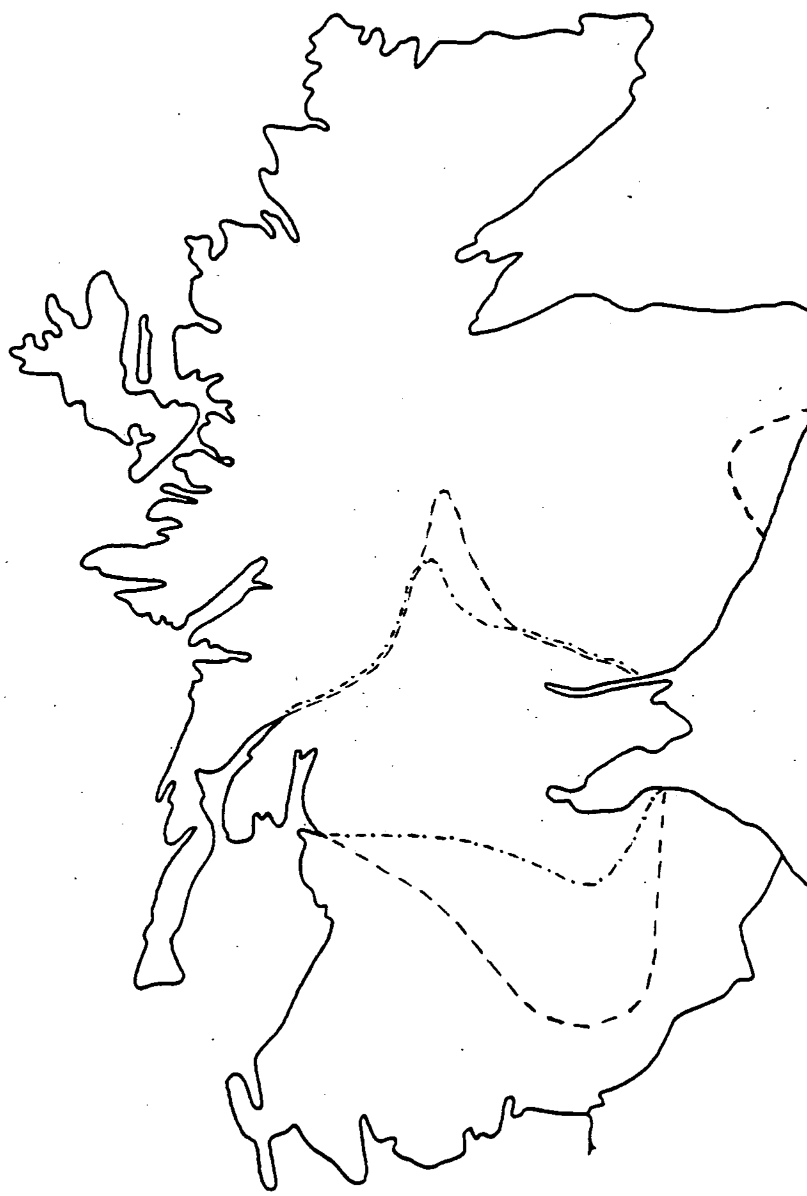
In the U.S.A. the grey squirrel is highly prized, providing sport, food and pelts but in Britain it is not regarded as a game animal and this might be one of the reasons for its quick and wide dispersal.

1.2 The problem of the grey squirrel as a pest

For about fifty years the grey squirrel has been regarded as a serious pest in Britain and a campaign to control it was launched in 1931 under the auspices of the "Field Magazine". In 1937 it became illegal to import or keep grey squirrels and from 1953 to 1958 a bounty scheme (one shilling for each tail, the reward doubled in 1956) was introduced to help restrict the damage they were causing, with little success (Shorten, 1957b).

FIGURE 2 : Range of the grey squirrel in Scotland.

Map scale 1:2000000



-.-.-.-.-.-.-.-.- Boundaries from F.C. questionnaire (1979)

- - - - - - - - - - Boundaries from S.W.O.A. questionnaire (1979)

Four main charges have been levelled against the species :

a) That it causes considerable economic damage in populations of young hardwoods mainly by bark-stripping.

b) That it is responsible for the decline of the native red squirrel.

c) That it eats birds' eggs and fledgelings.

d) That it raids orchards and gardens.

The first of these, the damage to hardwoods, is generally regarded as the most serious and it is this that is investigated in this thesis. It is worth pointing out at this stage that squirrels are not the only species responsible for bark stripping at the base of trees. Deer, rabbits, hares, voles and even live-stock show this behaviour in winter when food is short (Taylor thesis, 1969). Squirrels are exceptional in that, unlike the previously mentioned animals, they cause severe damage only during late spring to mid summer. It is of interest to note that this is in fact a time of food shortage for squirrels before the appearance of the autumn mast crops.

Bark stripping is a phenomenon rarely recorded in the animals natural habitat in the USA, except in suburban areas where the population is at a high density (Taylor, J.C., 1969). Nixon *et al* (1968) in their study of food habits of squirrels in S.E. Ohio did not report bark or cambial tissue consumption in their analysis of 604 examined stomachs. Several explanations have been suggested for this absence or low level of damage.

a) greater variety of alternative foods, to be had in cases of food shortage (Taylor, J.C., 1969).

b) greater numbers of predators which firstly, reduce the squirrel population and secondly, restrict some of their activities such as the time consuming bark-stripping (Taylor, J.C., 1969).

c) considerable reduction in their populations during the hunting season; (e.g. in Mississippi State, half the size of the U.K., the average annual cull during a three year census was 1,906,000 grey squirrels (Redmond, 1953).

Contrary to this satisfactory situation (i.e. no damage, food and pelts), the British hardwood forest is under continuous threat of damage from uncontrolled population levels either on local or national scale, because not one of the proposed methods to control grey squirrel numbers appears to be effective.

1.2.1 The nature of the damage to hardwoods

Existing data demonstrate that grey squirrels cause several types of damage to both hardwoods and conifers, by bark stripping and removing buds, shoots, flowers and seeds (Shorten, M., 1954; F.C. Leaflet No. 31; Taylor, J.C., 1969; Mackinnon, K. S., 1976). However hardwoods are generally more severely affected and some of these frequently suffer repeated injuries. Patches of bark are ripped off and the wounds according to their size and the location on the tree can create serious problems for the forest manager when large blocks of susceptible species of similar age are grown together.

1.2.1.1 Size of the wound

Little detailed information has been published concerning the size of the wounds. Most workers on the subject when they refer to bark stripping damage usually provide a general description of it ranging from negligible wounds up to complete girdling of the trunk (Shorten, M., 1954; F.C.Leaflet No. 31).

1.2.1.2 Location of wounds

Davidson and Adams (1973) described the locations on the tree where injuries may be found as follows :

a) Crown damage. This includes gnawing on foliage branches up to two centimetres thick.

b) Middle stem damage.

c) Damage at the base of the tree. Damage of this kind can also be done by a variety of other animals large and small, domestic and wild, especially by deer and rabbit.

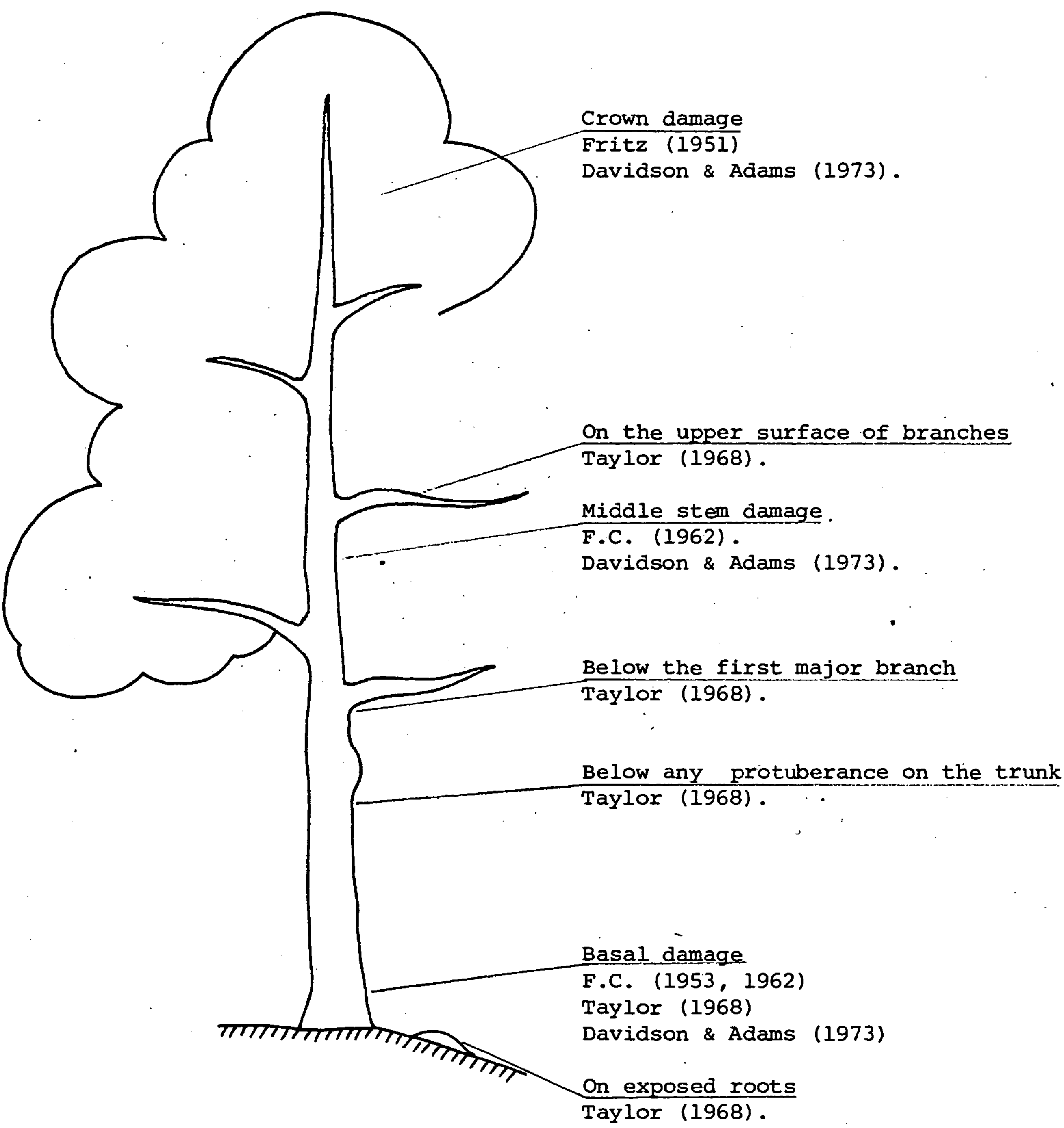
Fritz (USA, 1951) reported that squirrels damaged large saplings or the thin-barked areas in the upper crowns of the large trees. British workers described wounds, found near the butt and/or at about 30 cm above ground level, while the part of the stem between the basal zone and the first branch is seldom touched (F.C. 1953; F.C. 1962). Taylor (1968) noted that gnawed patches may be found in any part of the stem.

A pictorial summary of the location of the wounds, is given in Fig. 3.

1.2.1.3 The species affected

Marked differences exist between tree species in their susceptibility to bark stripping. Table 1 summarises the

FIGURE 3: Locations on the tree where grey squirrel damage can be found.



susceptibility of the various species as it has been recorded from various sources. Some species valuable for their timber such as sycamore and beech, are attacked more seriously than others such as birch or elm. In certain districts damage to sycamore has been so serious that it has raised doubts about future planting of that species as an economic crop (F.C. 1962). Damage to conifers done by grey squirrels has also been reported (Shorten, 1957a; Taylor, 1969), but Melville (1980) after a survey of eighteen estates in Scotland noted that from the wide variety of species and ages studied, bark stripping damage was found only on sycamore, beech and oak. No damage was found on any conifers.

1.2.1.4 Timing of damage

Grey squirrels in Britain have been recorded gnawing bark mainly during late spring and summer (Table 2). The behaviour seems to be irregular in its occurrence both from year to year and from place to place (F.C. 1962; Taylor, 1969; Davidson and Adams, 1973). Shorten (1957c) has suggested that gnawing occurs more frequently when the squirrel density is high.

Workers in the USA have described damage during winter (Brenneman, 1954; Irving and Beer, 1963). Burgess (1957) referring to gnawing of sycamore bark by squirrels writes : "Existing information comes mostly from North America, where Bailey (1946) has stated that bark peeling occurs in winter when maple seed is not available, due either to a poor crop or ice on the ground."

TABLE 2 : Timing of damage caused by grey squirrels throughout Britain by bark-gnawing.

Source	Author	Locality	Period of damage		Peak of damage
			Earliest	Latest	
Squirrels (published by Collins, 1954)	Shorten, M.	Not reported	mid April	No data	May - June
University Oxford Bulletin Dept.Forestry (1954)	Burgess,J.M.	Wytham Wood, Oxford	January	End of August	Mid June to mid July
Forestry (1957)	Shorten, M.	Throughout Britain	No data	No data	Late May to early August
Taylor, J.C. Unpub.Thesis (1969)	Taylor, J.C.	Berkshire	Late March	Late August	Late June to early July
F.C.Leaflet No. 56 (1973)	Rowe, J.J.	Not reported	May	July	No data
Q.J. For. (1975)	Davidson,A.M.	Not reported	April	July	June
Mackinnon,K.S. Thesis (1976)	Mackinnon	Berkshire	May	No data	Late June to early July
Q. J. For. (1978)	Davidson A.M.	Not reported	Forestry Commission observers report that there is in November another shorter outbreak of bark damage.		

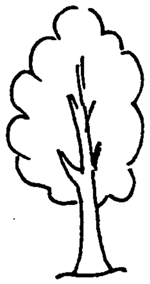
TABLE 1: Level of susceptibility of hardwoods to bark stripping by grey squirrels.

Source	F.C. 1953	Forestry 1957	F.C.Leaflet No.31 (1962)	F.C. Leaflet No. 56 (1973)	F.C. (1980) Closure report
Author	Unknown	Shorten, M.	Shorten, M.	Rowe, J.J.	Melville, R.C.
Locality	Not reported	500 state forests in England, Scotland and Wales	Not reported	Not reported	18 estates in Scotland
Highly susceptible	Beech Sycamore	Sycamore Beech	Sycamore Beech	Beech Sycamore	Sycamore Beech
Occasionally attacked	Oak Ash Birch		Oak Ash Birch Larch	No data	Oak
Seldom affected	Larch Scots pine	Oak Ash Birch and a number of other species	Scots pine	No data	

N.B. Such lists should not be regarded as constant because the needs of the plants and the motivations of the animals themselves may vary according to habitat. (i.e. elimination of one preferable tree species may increase the susceptibility of another lower in the rank.)

FIGURE 4: The Effects of Barkstripping

Effects on the



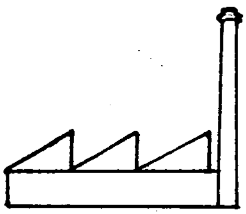
Individual tree

Primary
- Stem deformation
- Death

Secondary
- Reduction of growth rate
- Eccentric growth
- Infections and rot
- Increased risk from wind or snow breakage

Stand

- Weakness in the canopy and stem net
- Increased fire hazard because of the dead material



Industry

- Calluses or splits in the saw-timbers
- Weakness of the mechanical properties of the wood
- Discoloured timber
- Problems for the mechanical peelers

Forest management

- What are the final volume losses ?
- What are the losses in timber quality ?
- What is the control cost ?
- What tree species should be chosen ?

1.2.2. Effects of bark stripping

Figure 4 depicts what might be regarded as primary and secondary effects on the individual tree, the stand, the timber industry and the forest management.

1.2.2.1 Effects on the individual tree

It has been suggested that some tree species are most susceptible to damage when they are between 20 and 40 years old. No serious damage has been noticed in younger crops and in mature forest, even if squirrels are present, they do little damage (F.C. 1953, 1962).

Some workers held the view that bark stripping rarely affects the growth performance of the damaged tree. Pellew (1968) working on conifers damaged by deer in Lancashire noted that Wiedemann (1951), Ueckermann (1966), Schelling (1961) and other workers in the Continent all agree that the damage has no significant effect on height increment.

Pellew further suggested that effects on diameter and volume increment are negligible unless the stem is of low vigour or bark stripping exceptionally severe. McIntyre (1975), citing Luitjes work on damaged Corsican pine, notes that in Holland, wounds caused by red deer on more than 2/3 stem circumference could reduce height growth by up to 10 %, and mortality in stands with this size of injury was 23 %. On the other hand, Maxwell (1967) working with red deer in Western Scotland estimated that stripped pole-stage trees suffered a 40 % reduction in volume increment.

Whether the above mentioned conclusions can be employed for the hardwood species in my study area, it is hard to determine.

To gain more information about the affects on sycamore, beech, ash and oak trees when different fractions of bark have been removed, longer term assessments would need to be carried out.

However, there is little doubt, that bark-stripping can variously effect the individual tree. In particular, the following can happen.

On young trees, if the main stem is damaged by girdling a lateral branch functions as leader, with subsequent marked trunk deformation. If ringing occurs at the butt or the stem below the lower branches the tree dies after one or two growing seasons. If the size or location of the wound does not cause death, a reduction of the growth rate might be expected. In the case of serious wounds, which almost encircle the bole, markedly eccentric growth can result in permanent stem deformation.

Finally, exposure of the sapwood creates access for fungal infections and insect attacks. Abbott *et al* (1977) considered that grey squirrels may transmit the fungus *Cryptostroma corticale* which causes the sooty bark disease of sycamore.

The resistance to this sort of secondary damage varies among the different tree species. Of the major plantation species in the U.K., the spruces seem to be the most severely attacked by wood pathogens after bark stripping (McIntyre, 1975).

In those species prone to infections, the presence of large unhealed wounds leads, if heart rot occurs, to a severe reduction in the strength of their trunk, making the tree much more liable to wind and snow break. (Plate 1).

PLATE 1: Windsnap of pole stage sycamore (left centre midground) due to severe bark-stripping at the butt of the tree (foreground centre).

1.2.2.2 Effects on the stand

Stripping damage almost invariably means a reduction of the expected income. How large the losses are, depends on a number of factors.

a) The extent of damage (i.e. the proportion of trees damaged). The greater the number of affected trees at the early stages of growth, the less the final crop and subsequent income.

b) The severity of damage (i.e. the number and/or the size of wounds per injured tree).

c) The location of damage (i.e. the distribution of the damaged trees in the stand). The more clumped the distribution, the greater the weakness in the canopy and stem net and the bigger the danger from gales and snowfalls in exposed sites.

1.2.2.3 Effects on timber quality

Pellew (1968) considered that depreciation in quality following bark-stripping may be due to occlusion of dead phloem wood, discolouration of wound tissue and eccentric growth. If the wound does not encircle the trunk, the primary damage is restricted to that part of the stem in the immediate vicinity of the stripped area and thus only this section need be lost. Of potentially far greater degrading effect on the timber quality is the infection of the wound by decay fungi which greatly reduce the strength of the wood. McIntyre (1975) referring to conifers susceptible to heart rot, noted that the occurrence of rot can mean a reduction in quality from saw-timber to fuel-wood of up to 50 % of the timber volume of the stand.

Secondary damage by rot is probably of greater significance for the timber quality than the bark-stripping itself.

1.2.2.4 Effects on the forest management

Several investigators working with conifers bark-stripped by deer in the Continent, hold the view that silvicultural consequences are small unless the damage is extraordinarily severe (Pellew, 1968). Tittensor (1975) referring to red squirrel damage, suggested that when more than 20 % of the trees under fifty years old in a woodland unit are affected, the damage is usually considered serious enough to initiate some form of control measures. Obviously the consequences on the management are intimately bound up with the susceptibility of the tree species and the length of the vulnerable period.

In determining the optimum response to the problem, the forest manager faces some principal questions such as :

a) What are the revenue losses due to extension of rotation following a loss of vigour and/or the frequent premature thinning of stripped stands ?

b) What are the losses in timber value due to deformity of the stem and/or the fungal infection ?

c) What tree species should be chosen for future plantations ? Susceptibility to injuries, vulnerable period, resistance to secondary damage are some of the factors that should be taken into consideration. Some foresters advocate that the presence of animals causing considerable amount of damage should be regarded as a site factor in the same way as soil type or exposure (Müller, 1965).

d) What is the cost of controlling the damage ? The cost and uncertainty over a long period of time obviously mean that a great risk is being taken when vulnerable species are being grown, and that expenditure on control measures is likely to be high. This is a serious drawback when profit margins are small as they are in timber investments.

Other indirect problems also arise, such as limitation imposed on thinning operations, disturbance of the forestry development programme and disruption for some of the management objects (e.g. if uneven aged stands are sought for).

1.2.3 Reasons for bark stripping

A number of suggestions have been advanced to explain why squirrels strip bark and can be grouped as follows :

a) To obtain food or trace elements

b) As a form of social behaviour

c) To obtain nest material

d) To wear down incisors.

1.2.3.1 Bark stripping to obtain food or trace elements

At the outset it must be established whether squirrels actually eat the bark they strip or that they eat tissues exposed by the removal of the bark. There are a number of reports of squirrels eating bark (Davidson & Adams, 1973; Taylor, 1969) but these originate from observations whose validity is uncertain. There are no reports of bark being found in the stomachs of dissected animals.

However, fairly large quantities of cambial tissue were found in the stomachs of squirrels shot during the period when bark stripping occurred in a badly affected beech plantation (Mackinnon, 1976). Shorten (1957a) also suggested that cambium tissue is eaten by squirrels but it is not known whether the chief attraction lies in the water content of the sap or in the sugars and salts present.

Comparable information is available for some other bark-strippers, such as the red squirrels and deer. Tittensor (1970) studying the red squirrel in U.K. found that sappy tissue constituted one item of primary foods during early summer but it was also taken as secondary food in spring and late summer.

Stillinger (USA, 1944) observed a Richardson red squirrel which stripped the bark, licked the exposed surface but did not eat any of the bark removals.

Much more research has been done on bark stripping by deer and there is agreement that bark is taken for food, but opinions vary on whether trace elements, minerals, vitamins, alkaloids, roughage, energy-food substances, or even tannins, are the desired item (Mitchell, *et al* 1977).

1.2.3.2 Bark stripping as a form of social behaviour

A number of suggestions of this general type have been made but none has been investigated with any degree of thoroughness. Mackinnon (1976) suggested that bark stripping occurred during agonistic encounters when "subordinate" animals were forced into suboptimal habitats. Davidson (1975) advocated a similar hypothesis. Gnawing has been observed during courtship behaviour by male squirrels but the areas of bark removed in this seem to be very small (Davidson & Adams, 1973). Rowe (1973) has also suggested that some form of behaviour associated with mating may be responsible but again without any evidence. An interesting observation has been made by Taylor (1969). Apparently only a small number of animals in the population he studied were responsible for bark-stripping. This is consistent with the idea that some form of social behaviour is involved but it certainly does not exclude nutritional causes as different animals may have different nutritional requirements.

Again in this context it might be useful to consider the evidence relating to bark stripping and social behaviour in deer

(McIntyre, 1975) and red squirrel (Pulliainen & Salonen, 1963).

1.2.3.3 Bark stripping to obtain nesting material

Davidson & Adams (1973b) suggested that during the breeding season there is a regular demand for supplies of bark for lining the canopy dreys, or filling the cavity nests. They reported that a great part of nesting material in the cavity nests consists of bark. The raw material is taken from the tree in lengths of 15 to 60 cm and widths of 2.5 to 5 cm and carried to the nest where the cuticle and cork layers are removed. However, it is not made clear if the bark used as lining material was peeled off live or dead parts of the tree.

1.2.3.4 Bark gnawing to wear down the incisors

It has been conjectured that among animals feeding on soft foods, it is a necessity to wear down their continuously growing incisors by gnawing on hard materials (Davidson & Adams, 1973). However this explanation is doubtful because the squirrels turn to smooth barked species such as sycamore and beech in the pole stage while rough barked trees such as oak, elms or conifers are readily available (see Table 1).

1.2.4 Which animals do the damage ?

Information on the identity (age, sex, social position) of grey squirrels known to be responsible for bark stripping could be very valuable when trying to discover why the behaviour occurs. However, published information is very limited (Table 3).

TABLE 3 : Some records in which grey squirrels were seen to strip off bark.

Source	Observer	Locality	Juvenile & Subadults Female	Juvenile & Subadults Male	Adult Female	Adult Male
Taylor, J.C. 1966	Taylor	Berkshire				1
Taylor, J.C. 1969	Taylor	Berkshire	√	√		
Davidson, 1975	Forestry Commission workers	Not given			√	
Mackinnon, 1977	Mackinnon	Berkshire	3*	9*	1*	2*

Remarks:

√ = Number of observed animals is not given

Digit = The number of animals seen to strip off bark

* = Results from stomach analyses of 30 squirrels killed during the damage season of which only 15 had cambial tissue in their stomachs.

1.3 The biology of the grey squirrel in Britain

1.3.1 Breeding of the grey squirrel

Individuals of both sexes may frequently be seen together but they do not form permanent pairs. They have two mating seasons, one in mid-winter (January) and a second about June. Gestation lasts for about 6.5 weeks. Young when born, are blind and naked and remain in the drey for about 7 weeks before they are able to emerge and forage (F.C. 1962).

Litters average 2.5 - 3.2 but the size possibly depends on the age of the female and the diet available immediately before and during the breeding season (Shorten, 1951). The summer litter probably has a better chance of survival since it is borne in a more favourable season. Young take from 9 - 13 months to become sexually mature, so they are not ready to breed until the year after their birth (F.C. 1962).

Summarising the existing data, it could be said that during the bark stripping period, (May to August) some adult females are in breeding condition; some in gestation and some in lactation while the adult males are in breeding condition and the offsrping are old enough to forage independently.

A simple but comprehensive chart showing the breeding biology of the animal and drawn up by Shorten (1954) is illustrated in Figure 5.

Food

The qualitative food preferences of the grey squirrel have been determined by a number of workers, mainly by observing the animals feeding (Middleton, 1930; Shorten, 1954; F.C. Leaflet No. 31; Taylor, J.C. 1969). Stomach content analysis is difficult because of the efficient mastication and studies based on large samples of stomachs are few (Nixon, M.C. *et al* 1968; Mackinnon, K.S. 1976).

Existing data indicate that the animal's diet varies seasonally and also from one area to the next. The following items have been recorded in the diet of wild squirrels. Mature seeds from the previous autumn (mainly nuts, acorns) and wild fruits, bulbs, bird's eggs, buds, shoots, woodland fungi, crocus corms, oak galls, flowers, bark, larval and adult insects, immature seeds, cereals, grain, domestic fruits, berries, maturing and mature seeds of the year's mast, and sometimes carrion and honey.

Information for the bark stripping period (May to August), is of particular relevance to this study. Nixon, M. C. *et al* (1968) noted that in May and June there was a peak in the consumption of plant fragments (leaves, roots and fibres). Mackinnon (1976) found that stomachs of animals shot in a damaged beech plantation during June and July contained large quantities of cambial tissue and bark (up to 82 % of the volume of stomach contents in June). Taylor, J.C. (1969) with over a thousand observations of animals feeding, noticed that during the May - August period, the food items eaten were bark, flowers, developing nuts and nuts of beech, sycamore flowers and keys, birch seeds, insects, fungi and cones. The same author described the case of one grey squirrel taken while stripping bark from sycamore. Its stomach was found to be packed with the soft cambial tissue but there was no trace of the hard suberised layers.

X028274

If not collected return to:
INTER-LIBRARY LOANS,
1993 MAIN LIBRARY, UCNW.

Please ensure reader signs both copyright declarations before reading.

n the
the
with
Also,
quent

)

MISS LM BEAVIS
FORESTRY AND
AGROFORESTRY,
S.A.F.S.
UCNW

MISS LM BEAVIS

Due: 25 MAY 1993

PING BY GREY SQUIRREL

1983

FROM THE LIBRARY. I will ensure
my possession and I will return
before closing time

UNIVERSITY COLLEGE OF NORTH
INTER-LIBRARY-LOANS
****

RESTRICTED ACCESS

The following item has been lent
condition that it is consulted
LIBRARY. Please call at the SERVI
this notification before 28 APR
bring this notification on each
visit.

DUE BACK: 25 MAY 1993 (CAN NOT B

PETAMEDES,G.S.
STUDY OF BARK STRIPPING BY GREY
IN DALMENY ESTATE
M.PhIL, EDINBURGH, 1983

UNIVERSITY COLLEGE OF NORTH
****

RECEIPT FOR RESTRICTED ACCESS MATERIAL

I acknowledge receipt of: PETAMEDES,G
STUDY OF BA
IN DALMENY
M.PhIL, EDI

and I understand that this must NOT BE
that it receives all reasonable care w
it to the ILL OFFICE not later then
earlier time if requested to do so.

DATE & TIME OF ISSUE	READER

FIGURE 5 : The breeding cycle of the grey squirrel in Britain.

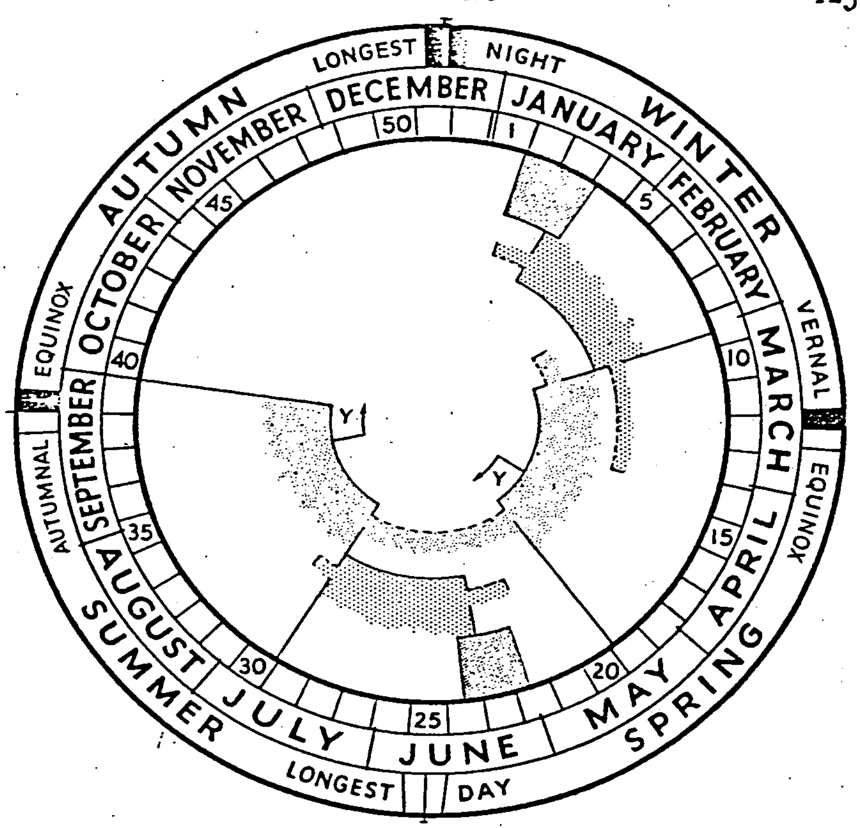


FIG. 18
Yearly cycle chart showing the breeding seasons of the grey squirrel in Britain, as observed from samples shot in various localities. Some animals with early pregnancies must have had oestrus periods earlier than those observed

Y *Young begin to emerge*
lactation
pregnancy
oestrus

Source : Shorten, M. (1954) "Squirrels".

The New Naturalist Series, Collins (London)

A I M S

AIMS OF THE STUDY

When the campaign against grey squirrels was launched in 1931, two objectives were set. Firstly, to check the spread of the species throughout Britain and secondly, to control squirrel numbers where populations had become established. Neither aim has met with success.

Since 1952 most of the relevant studies on the bark-stripping problem by the Universities, the Ministry of Agriculture, the Forestry Commission and individuals have been focussed on the grey squirrel's biology, so that proper methods could be developed and the damage could be prevented. In 1978 D. A. Wood suggested : "...as the only really feasible solution to the squirrel problem, I strongly urge the setting up of an independent Squirrell Research Unit". The statement above, after almost 35 years of continuous efforts, demonstrates that the problem is still topical, as the animal's range is expanding and damage is increasing at a significant rate (SWOA survey, 1979).

There are three possible strategies for coping with the grey squirrel bark-stripping problem.

Direct population control

Manipulation of the environment

Socio-economic changes

2.1 Direct population control

The grey squirrel population has continued to increase and expand its range despite control efforts. Either the efforts have not been intense enough or the methods used have been inappropriate. Direct population control requires a continued expenditure. It is not known what level of expenditure is required at present to reduce the populations to a level at which damage is acceptable nor is it known how this expenditure might change in the future. Control efforts might in many areas always be vitiated by the presence of reservoirs such as parks and gardens where control may not be possible.

Even if direct control is adequate in some places it is desirable to have another strategy available for use in conjunction with direct control or as an alternative.

2.2 Manipulation of the environment

The presence of grey squirrels in an area is dependent upon the required set of environmental conditions. Similarly, economic damage might occur only under certain conditions. It might therefore be possible to alter conditions to reduce the squirrel population or reduce the amount of damage done. This has an advantage over direct control in that recurrent labour costs will most likely be considerably lower.

2.3 Socio-economic changes

This third alternative would involve a dramatic change in human values such that lower timber production, lower profit margins or higher timber costs would be acceptable. This kind of alternative solution seems unlikely although it might be forced upon society if other alternatives fail.

The aim of this project was mainly to investigate the second of these alternatives (habitat manipulation) although some information was also collected that is relevant to the first option. This study was undertaken firstly because most previous work had been carried out in the South of England and it was thought that it would be useful to contribute some information from Scotland. Secondly, most past work considered damage accumulated over several years while this study mainly looks at new injuries. Thirdly, this study considers some questions not previously studied in detail - whether some tree species are attacked earlier than others; how many new injuries start from intact bark and how many from healing wounds; the average dimensions of new injuries; which plant tissue is eaten by the squirrel; whether squirrels attack the same tree repeatedly within one bark-stripping period; these and other questions are described in later chapters.

Three approaches were used in this study -

a) Close study of the new injuries

b) Investigation of reasons why the animal strips bark during a limited period of the year

c) Investigation of correlations between the seriousness of damage and management or environmental factors.

As a result of these investigations it was hoped to suggest ways to minimise the level of damage.

S T U D Y   A R E A

3. THE STUDY AREA

The main requirement of a study area was that it should have plantations of young, broad-leaved trees growing in a wide variety of situations and exhibiting a range of levels of grey squirrel damage.

The site chosen to meet these requirements was the Dalmeny Estate in the County of West Lothian.

3.1 Location and Ownership

The study area is approximately rectangular with its longer axis lying NW to SE, bounded in the SE by the river Almond, in the SW by the A90 and B924 and in the NW and NE by the shoreline of the Firth of Forth (Fig. 6). The total area enclosed by these boundaries is about 747.4 ha, of which one third (about 232.4 ha) is mixed woodland and two thirds (about 515.0 ha) is arable and grazing land, roads and buildings.

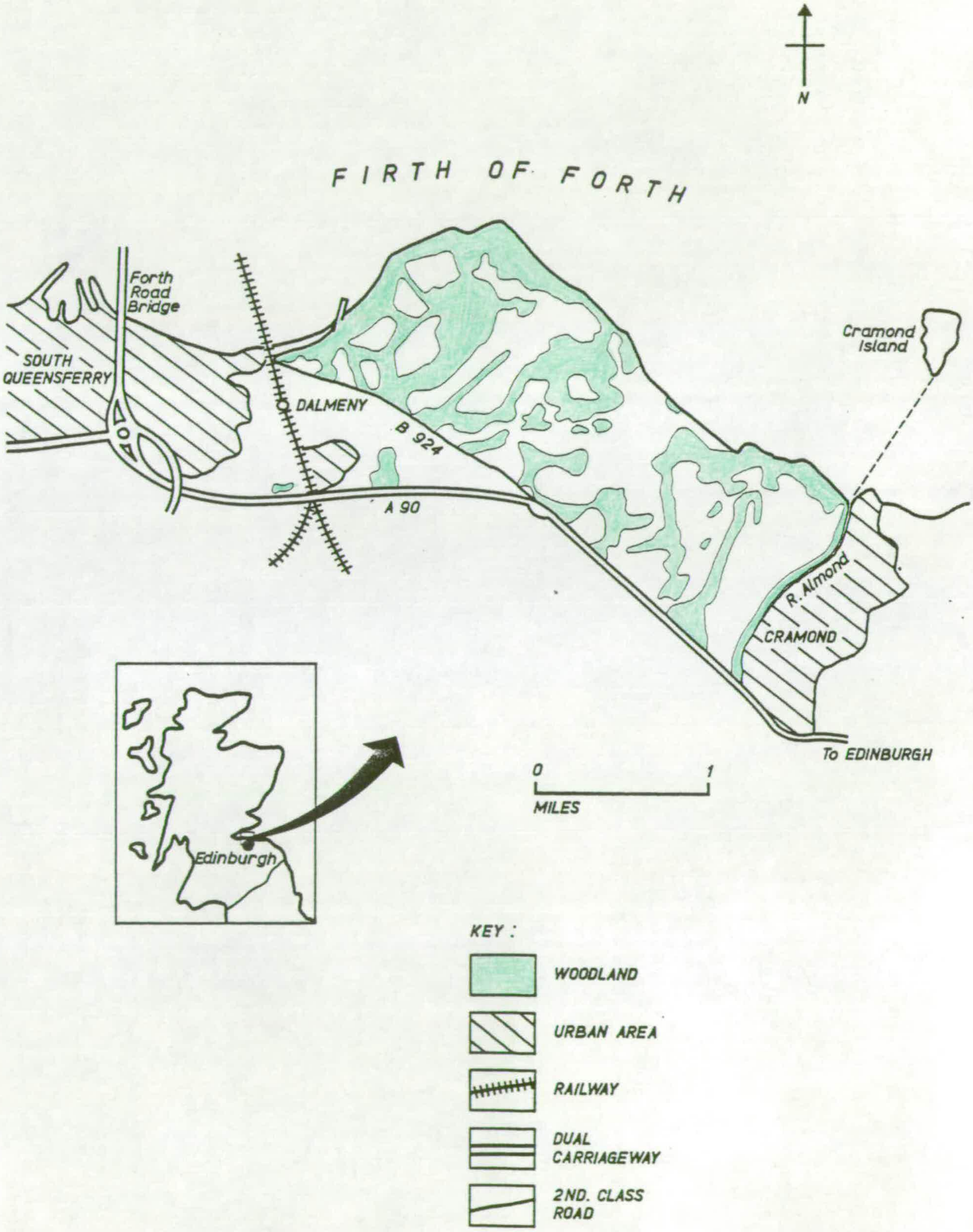
The sector over which the woodlands are spread, lies between 3° 18' to 3° 23' W longitude and 55° 58' to 56° N latitude and it is covered by the Ordnance Survey map, sheets (NT 17 NW) and (NT 17 NE) 1:10000.

The estate is owned by the Earl of Rosebery, Dalmeny House, South Queensferry. The area is closed to the public except for the shore walk from South Queensferry to the ferry over the river Almond at Cramond.

3.2 History of Land-Use

The late Professor M. Anderson of Edinburgh University has summarised the history of the management carried out in the Dalmeny Estate (Anderson, 1956).

FIGURE 6 / LOCATION OF DALMENY ESTATE



Primeval Condition

Originally the area was covered by a rich flora of broadleaved species. The major tree-species may have been oak, ash and elm, with aspen, birch, willows and possibly yew the main secondary species. These woodlands were cleared for grazing and it is not improbable that, by the end of the 16th century, very few trees were left.

Recent History

Most of the older woods and shelter belts that exist today were planted in the 18th and 19th centuries to integrate with farming activities. The first management aims were to make the best use of the poorest and steepest land, unsuitable for farming, to grow timber and to protect the farm lands from the cold winds.

More recently, the woodlands have been valued mainly for sporting purposes but little in the way of felling and planting has been subsequently carried out.

In 1956, the greater part of the woods (179.2 ha) was dedicated under Basis II (i) and regeneration was started on a Group Selection System (ii) (Gurnaud-Biolley Check method), under the guidance of the Forestry Department at Edinburgh University. The suggested group size was about 500 m^2 (0.13 of an acre).

3.3 Topography, Altitude

Altitude ranges from sea level up to 119 m at Mons Hill in the north with a second peak (82 m) near the centre of the area. There are other minor ridges, the main direction of which is from E to W.

All aspects are represented and the degree of slope varies from very steep to flat. Most of the woods occupy the tops and upper slopes but there are some stands on low ground along the shore. Locations of the compartments and their size in hectares, are given in Figure 7.

3.4 Geology

The hill-tops and ridge-tops almost all consist of basaltic outcrops which intrude through the main matrix of the carboniferous strata. On the western slopes the soils may be very shallow and near the rock, but on the eastern slopes there is heavy boulder till extending up from the hollows. These drift deposits consist largely of debris from rocks of the carboniferous strata and are thus very rich in soluble mineral matter. In some of the hollows, peat has formed but it is of a loose, friable texture and rich in minerals. In some areas along the line of the shore the sandy appearance of the soil is quite obvious.

3.5 Soils

The soils are chemically very base rich, even on the shallow basalt outcrops. The majority consist of dark loams of a loose texture, sometimes mixed with rock debris on the hill tops and upper slopes. On some of the western slopes with rock near the surface, the soil is of a pseudo-rendzina type - dark very loose and granular.

The depth of the soil varies, from almost nil to 60 cm or greater at the base of some slopes. In general, except near some open margins, the woodland soils are of excellent quality.

3.6 Climate

The area lies within the climatic sub-region Cld.* Average annual rainfall 716.1 mm. The humidity is high and there are from 25 - 50 days with frost. The growing season is over 190 days. Wind direction mainly from West to South but in early summer from Northeast to East.

3.7 Vegetation

The open-ground cover consists almost entirely of moist grass-herb types, rich in species, and of various ferns. Patches of Dog's Mercury (*Mercurialis perennis*) occur and Red Campion (*Silene dioica*) is frequent. On the heavier soils ground ivy is common along with Stachys and other herbs. On the shallower soils Brachypodium is fairly abundant. All the above mentioned species reflect the high base content of the soil. In the openings there is dense bracken. Species that compose the shrub and canopy layers are given in Appendix I.

The first management plan set five objectives in the following order of importance.

1. Timber production in perpetuity.
2. Protection of farmlands and neighbouring buildings from climatic conditions.
3. Creation of important elements in the amenity of the estate from both the ornamental and the recreational aspects.
4. Possibilities for the University and its students to study the Group Selection System.
5. To achieve an uneven-aged stand structure.

---

* Anderson, M.L. and Fairbairn, W.A. (1955) Division of Scotland into Climatic Sub-regions as an aid to Silviculture. Bulletin No. 1, Forestry Dept., University of Edinburgh.

This was carried on until the mid 1960's by which time it was decided that the groups were much too small and that larger groups of 0.3 to 0.4 ha, would be more easily managed. At this stage further woodland areas were added to the Dedication Scheme. However three unpredictable events (the 1968, 1974 gales and the 1977 outbreak of elm disease) occurred which disrupted this well organised plan of work.

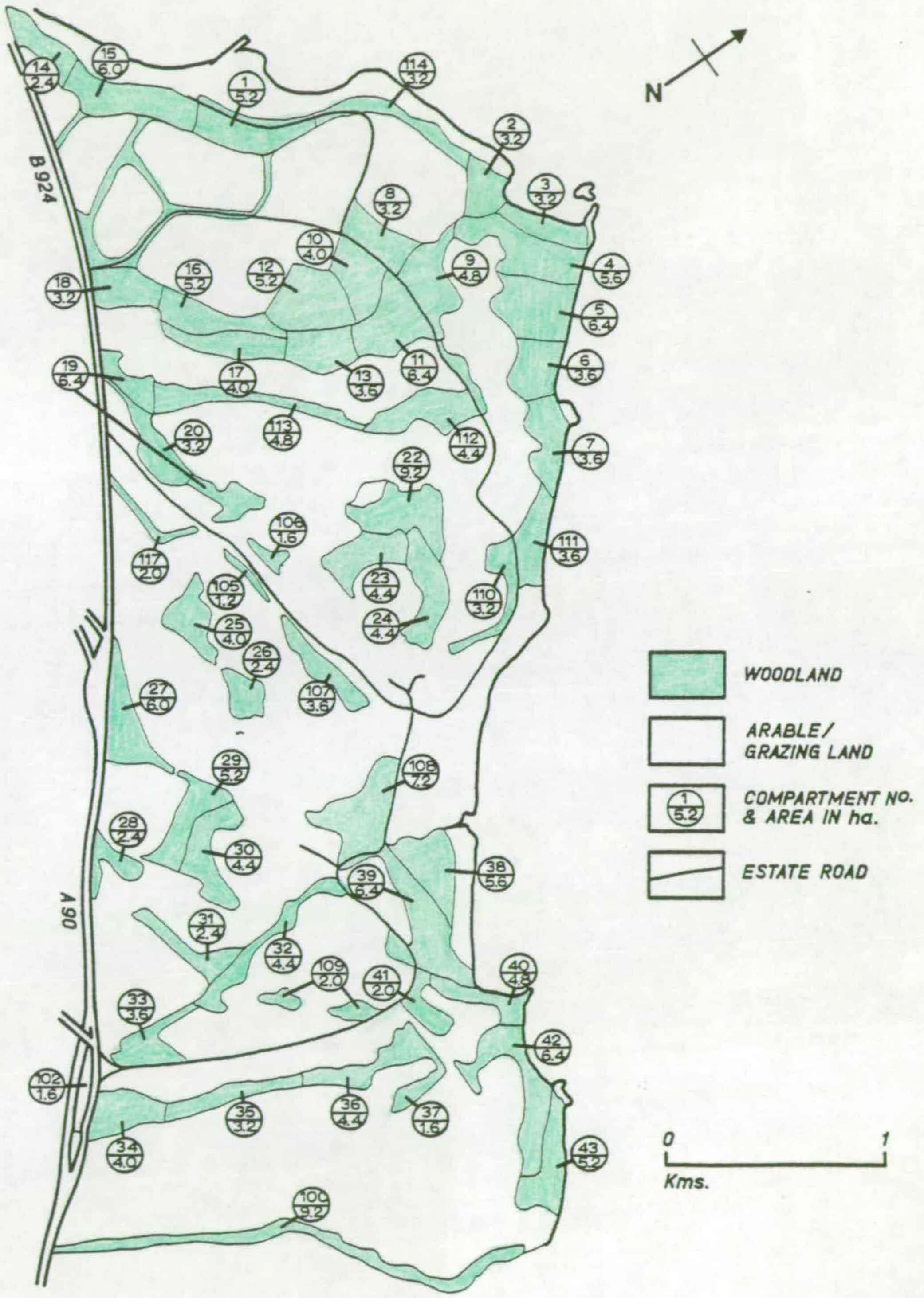
During 1977/78 it was decided to change from Basis II to Basis III as all the larger woods are based on a broad-leaved crop of a mixed age with some conifers which amount to about 10 % of the growing stock.

The recent management plan (1977) has set the following objectives :-

1. To manage the woodland in such a way as to produce in perpetuity the maximum quantity of the most valuable forest products.
2. To safeguard any designated ancient monuments in accordance with the relevant statute.
3. To ensure good land use including effective integration with agriculture.
4. To ensure environmental benefits, particularly visual amenity for both the owner and the public.
5. To provide such opportunities for recreation as may be appropriate, including sport.

The study area encompasses 54 compartments of varied shape and size (from 1.2 to 9.2 ha) (see Figure 7).

FIGURE 7 / LOCATION OF COMPARTMENTS WITHIN STUDY AREA



3.8 History of Damage

Squirrel damage in Dalmeny Estate was first reported by the late Professor Anderson (1956) who noted that "rabbits have been very numerous in the past and have been responsible for the elimination of some species, such as ash. The scarcity of young beech and oak may also be due to their depredations. Squirrels have also been very destructive to poles and saplings of broadleaf species, especially those with smooth bark, such as ash and sycamore".

Professor C. J. Taylor at Edinburgh University, after a visit to the Estate in 1973, reported - "Squirrels have caused considerable damage in old plantations, particularly sycamore stands".

Apart from grey squirrels, other animals responsible for the bark stripping (at least at the butt of the trees) are rabbits and roe deer. The native red squirrel is no longer found in this area and any reference in this text to squirrels will mean grey squirrels.

In the recent plan of operations for the years 1977/81, reference is made to the necessity for control of grey squirrels and of rabbits.

The foregoing information shows that the squirrel damage in the study area has attracted the attention of the forest managers for the last 25 years and that the problem remains unsolved.

M E T H O D S

METHODS

It has been reported by Shorten (1957a) that grey squirrels attack sycamore from 0 to 60+ years of age while beech is damaged most often between the ages of 10 and 50 years. Mackinnon (1976) found that bark-stripping in young beech plantations occurred significantly more often on trees of girth greater than 20 cm, while Rowe (1973) suggested that pole stage beech and sycamore are most often severely damaged.

Since one of the objectives of this project was to study the new injuries it was thought convenient to focus observations on the most vulnerable stands. During 1979 when the whole woodland area of the estate was visited it became clear that very young stands (seedlings and thickets) or timber stage stands did not display any serious accumulation of injuries.

The study set out to associate the relative frequency of damage with tree species, vulnerable dbh classes, parts of the tree usually affected and time of occurrence. Therefore it was decided to examine all the sapling and pole stage stands. However 19 stands which consisted of seedlings, thickets or pure conifer plantations were also inspected during the field work. These young plantations were examined 5 times throughout the study period but no serious damage was recorded.

Having obtained a general picture of the seriousness of damage all over the estate, the next consideration was to choose the stands best suited for the study.

4.1 Survey methods

Three sampling methods have been used by Forestry Commission workers, to assess damage done by deer.

a) The walk through method

b) The 100 sq. metre plot method, and

c) The nearest neighbour method.

The above approaches were not suitable for the present study for two main reasons.

Firstly, the study area consisted of a large number of small stands, often of mixed species. The above methods were devised for work in large single species plantations. A preliminary survey of the study area suggested that damage of a localised nature could be expected. Thus, it was thought better to obtain data from all the vulnerable stands. Only in this way could the questions posed in the study be adequately answered.

Another consideration was that most of the stands involved were of small size (between 0.05 to 0.07 ha). Inspection of all the trees was therefore feasible and in practise even less time consuming than the alternative of sampling by random selection. Plots within this size range had usually a maximum of about 30 trees of the studied species. Random sampling would have resulted in inadequate sample sizes.

Random sampling within the stand was used when stand size was greater than 0.07 ha. A random table was used letting the first two digits stand for a row and the next two digits designate the tree within that row (Freese, 1962).

4.2 Field work

Field work was carried out from April, 1979 to August, 1980. The study area was visited throughout this time but visits were more frequent during the period when damage was expected (see page 10). No obvious injuries were noticed outside these periods.

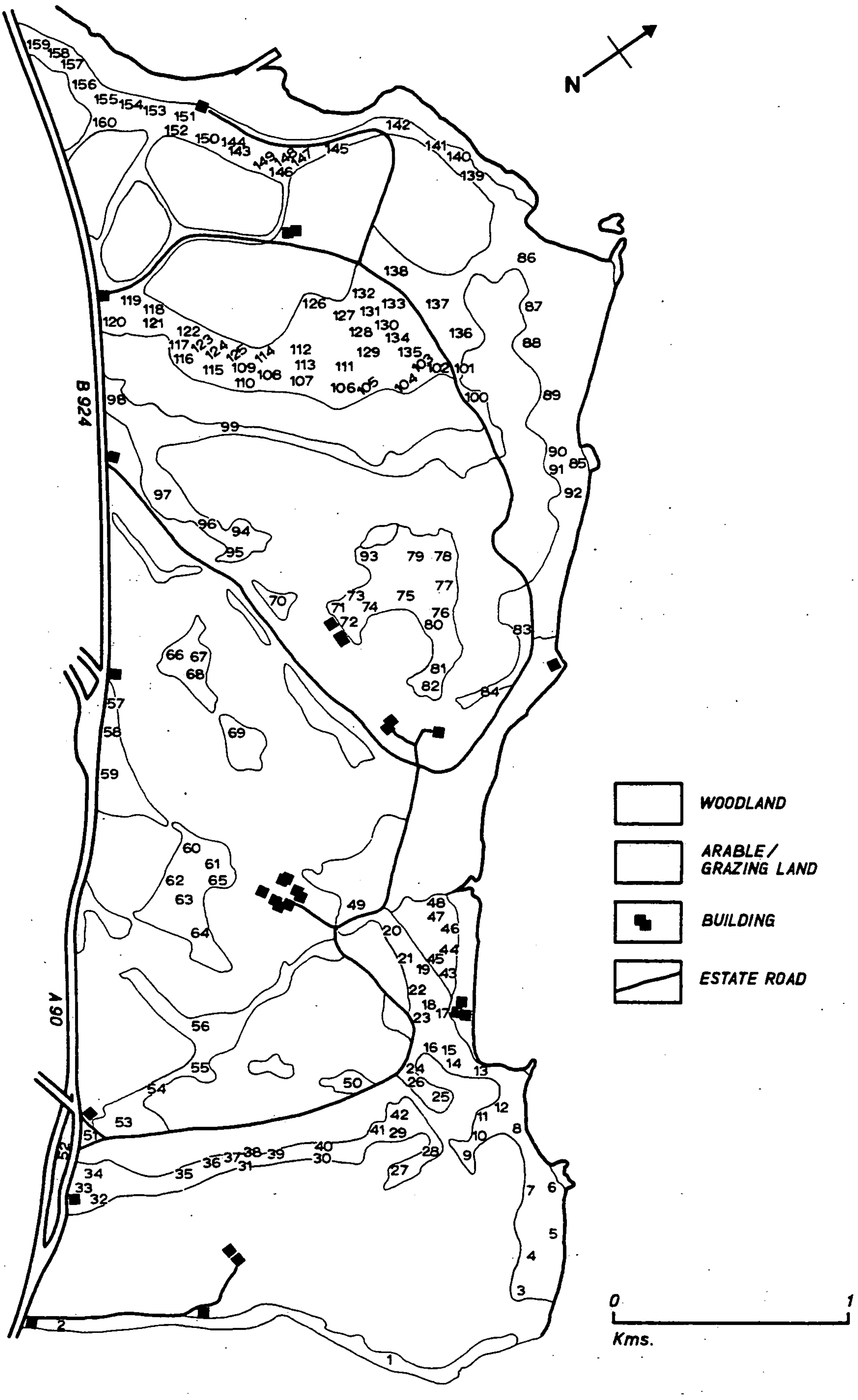
In April 1979 all of the stands in Dalmeny Estate were visited to gain a rough idea of the extent and seriousness of previous damage.

During May, 1979, the survey of the woodland area (Fig. 7) was completed and 160 stands were mapped (Fig. 8). These stands (which hereafter will be referred to as plots) were of varied species mixture, age, size and location. Additional pieces of information, such as exposure, silvicultural operations, fencing, slope and ground vegetation were also recorded in order to consider their significance (if any) in the bark stripping problem. Information of this kind is summarised in Appendix II.

In early June 1979, three plots (9, 102, 104) were chosen for an intensive study of new injuries. In the biggest of these plots (plot 104, 0.39 ha) a complete enumeration of the trees was carried out. Small wooden labels (5 x 4 cm) were fixed to identify by species and d.b.h. (diameter at breast height), each of the 1336 trees which were there. Each tree, according to its d.b.h. and position was plotted on graph paper (scale 1:200).

During June to September 1979, the plots (9, 102, 104) were inspected every two or three days and detailed notes were kept when new injuries were encountered. The data included the

FIGURE 8 / LOCATION OF THE PLOTS INSPECTED DURING THE STUDY



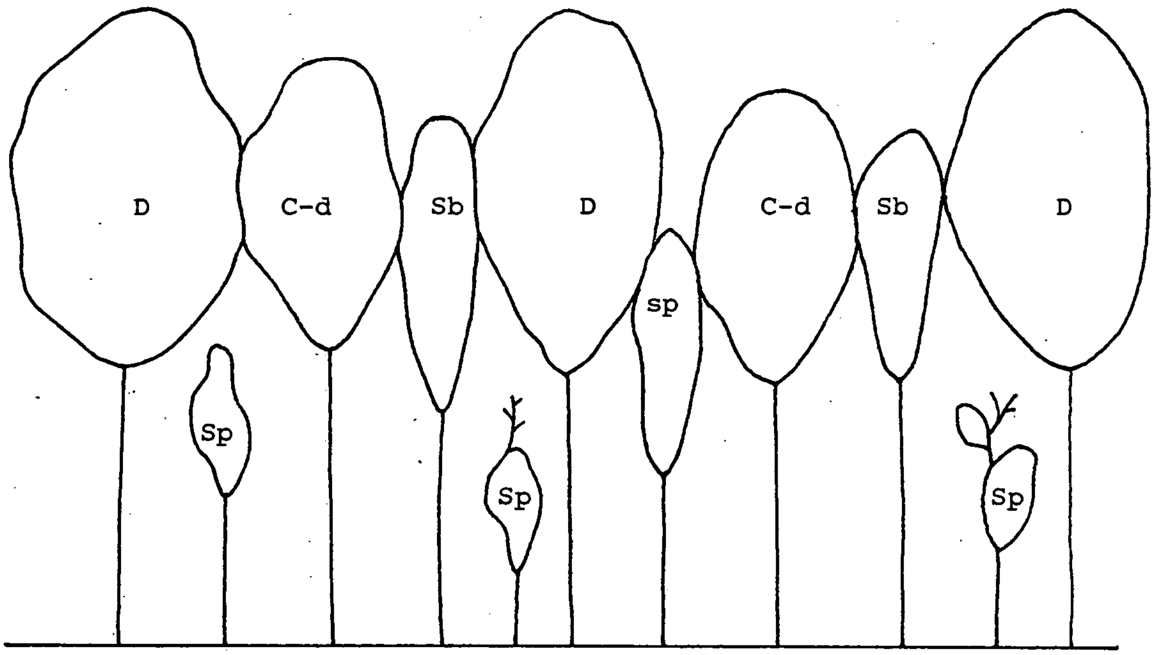
estimated date of injury, number of injuries on the same tree, wound dimensions, location and aspect on the stem, appearance of the injured surface and starting point of peeling (i.e. from bark or callus tissue).

During October to mid December, 1979 the remaining 157 plots were surveyed for past years' cumulative damage. This was found to be the best time to assess stem injuries since the trees were leafless. In overcast conditions it was found that some injuries were missed and observations were therefore made on sunny days. Each stem was measured with a rounded down diameter tape and its class of d.b.h. was recorded. Then the individual tree was inspected for injuries of any size and age at the butt, stem and/or branches. For each plot, all the known information was entered in a format which is shown in Appendix III.

During January and February, 1980 the number of plots for intensive study was increased to 6 by the addition of plots 5 (0.27 ha), 50 (0.48 ha) and 115 (0.05 ha). Altogether the six plots gave a good representation of the sizes, ages, and locations of plots on the estate.

In late February and March the three plots (5, 104 and 115) were inspected to record the flushing of the trees and their social position. The social position was recorded on the basis of the dominance of the crown relative to surrounding trees. Four categories of crown dominance were recognised; dominant (D), co-dominant (C-d), sub-dominant (Sb) and suppressed (Sp)(Fig. 9) (Chapman, H.H., 1931; Toumey, J.W., 1947). Visits every two or three days continued until August, 1980 in order to record the

FIGURE 9 : Classification of trees in the stand.



D - Dominant trees:	These are the tallest in the stand
C-d - Co-dominant:	These are shorter than the dominants, and usually to some extent shut in.
Sb - Sub-dominants:	These do not enter into the upper canopy, but are not directly overshaded by others.
Sp - Suppressed:	These have no direct access to light and stand beneath the crowns of adjacent trees.

injuries incurred during the 1980 bark-stripping period.

Finally, the rest of the 154 plots were visited between 10/6 and 25/7/80 to record the cumulative injuries that had been sustained during 1980. Estimates of the dates the injuries had been received, were made according to field experience. The day when damage was done, or was thought to have been done, was determined by the colour of the wound surface, extent of callus formation and general appearance. This is described in Appendix IV.

4.3 Classification of damage on the individual tree

The term "damage" has frequently been used, to describe wounds of any size. It would be more suitable if the term damage was used only when the size and/or the location of the injury had some serious effect on the injured tree.

The general term "injury" could be used to describe the whole range of wounds from the barely detectable tooth marks, up to the bigger stripped-off patches or to girdled stems. Small size injuries indicate attempts to remove the bark which are probably abandoned either because of difficulty with stripping or undesirable taste. When bark is ripped off in bigger patches, the resulting damage can be serious and even fatal.

Since exact information does not exist about the seriousness of damage in relation to wound size on the broadleaf species studied (Melville R.C.; Boyce, J., personal communication) the following arbitrary terms described below and pictured in Fig. 10 were employed in this work.

Trace: Tooth marks made by the lower incisors, each approximately 1 mm wide; easily recognised when they are fresh and the trunk is scanned at close quarters. Effects negligible.

Gnawing trials: This term has been previously used by Davidson (1975) to describe small wounds 2.5 cm or so across in the transverse or long axis of the stem, often seen on oaks.

In this work, the term is used to describe any injury bigger than trace and up to 10 sq. cm. (this upper limit was employed after the 1979 field experience and represents the average size of wounds that seem to be easily healed). Infections from pathogens are the major possible effects on the injured part of the tree.

Damage: This term includes all the injuries greater than 10 sq. cm. up to girdling of the stem. Trying to describe the pattern of single wounds it was found that the majority of them were elongated in shape. (see Appendix IV). Length and width were measured at the longest and widest points of the wound and its approximate area was estimated. In particular, the following terms were used :

Light damage: This describes the situation when up to 15 % of the bark circumference has been removed.

Moderate damage: When 16 - 50 % has been removed.

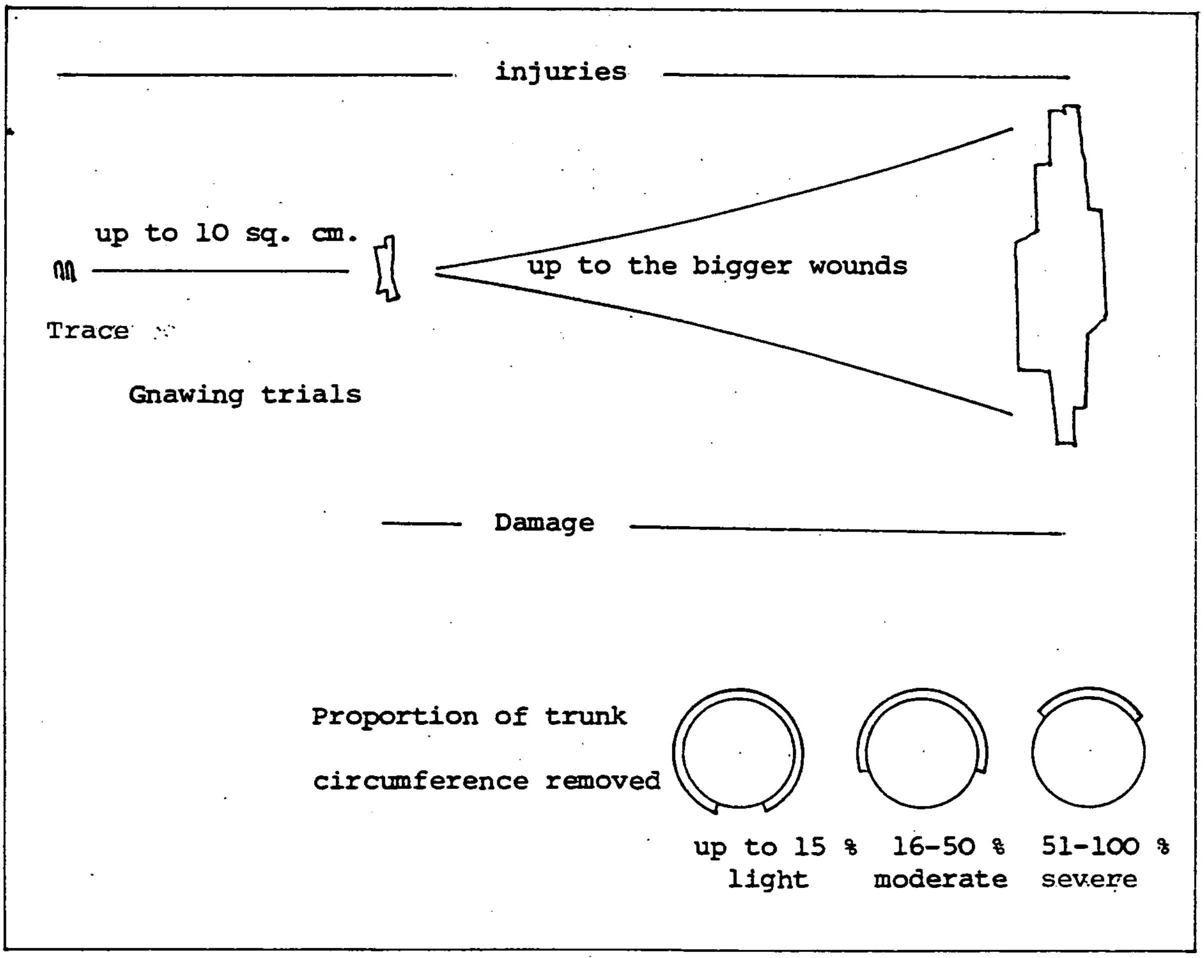
Severe damage: When 51 - 100 % has been removed.

Apart from the primary effects, a greater risk of secondary damage by microorganisms, broken tops, timber defects, losses in girth and height increment and finally death can be expected as a result of the above types of "damage".

When squirrel damage is fresh, it is easy to distinguish it by the size of the incisors marks. However, after a few weeks this is virtually impossible and may be confused with damage done by rabbits.

Shorten (1957a) noted that rabbits do not leave shreds of bark and this provides a means of distinguishing the animal responsible for any damage on the butt. However, rabbit damage is not common during the summer (Boyce, J, personal communication). Bark-stripping by rabbits occurs mostly during the winter, when a lot of snow is on the ground or food is generally in short supply.

FIGURE 10: Terms used in this study to describe various wounds according to their size.



4.2 Location of the plots

The position of the plots was related to standard points on the Estate map (scale 1:10000). The distance from these points was estimated by pace and compass. As this method can be inaccurate over varied terrain, allowance was made for slope when necessary during the conversion from paces to metres.

Secondly, using compass bearings and pacing along fence remains or stand boundaries, the outline of the plot was mapped using a scale 1:1000. The size in square metres was then calculated.

It was found that 48 percent of the plots were small, between 350 and 700 square metres, which is very close to the size (0.13 acre) proposed by the late Professor Anderson as the best size for regeneration groups in the Estate. The remaining plots ranged from 800 to 63700 square metres but the majority were between 1000 to 2000 square metres. In the few very large plots most of the area was occupied by conifers.

4.5 Discarded bark fragments

It has been suggested that one of the possible causes for bark-stripping by squirrels is to obtain nesting material (see page 20). To investigate this possibility, a total of 6 fresh injuries were studied in detail in 1979 (four sycamore and two beech wounds). When a very fresh wound was encountered, all the bark fragments were collected from the ground and were put in a plastic bag to keep them moist and flexible. Then the outline of the injury on the tree was drawn using a flexible piece of transparent plastic pressed against the trunk and tracing the outline with a fine tipped felt pen. When the damage is very fresh (i.e. a few hours old) the discarded flakes are not shrivelled and can be easily photocopied (the bark surface up) giving a clear image of their perimeter. Using an ordinary planimeter the area of the wound and the discarded flakes from that wound were easily calculated, and thus a size comparison between them was feasible. In all six cases it was found that discrepancies between wound size and total flake area, were negligible. An example is illustrated in Figure 11.

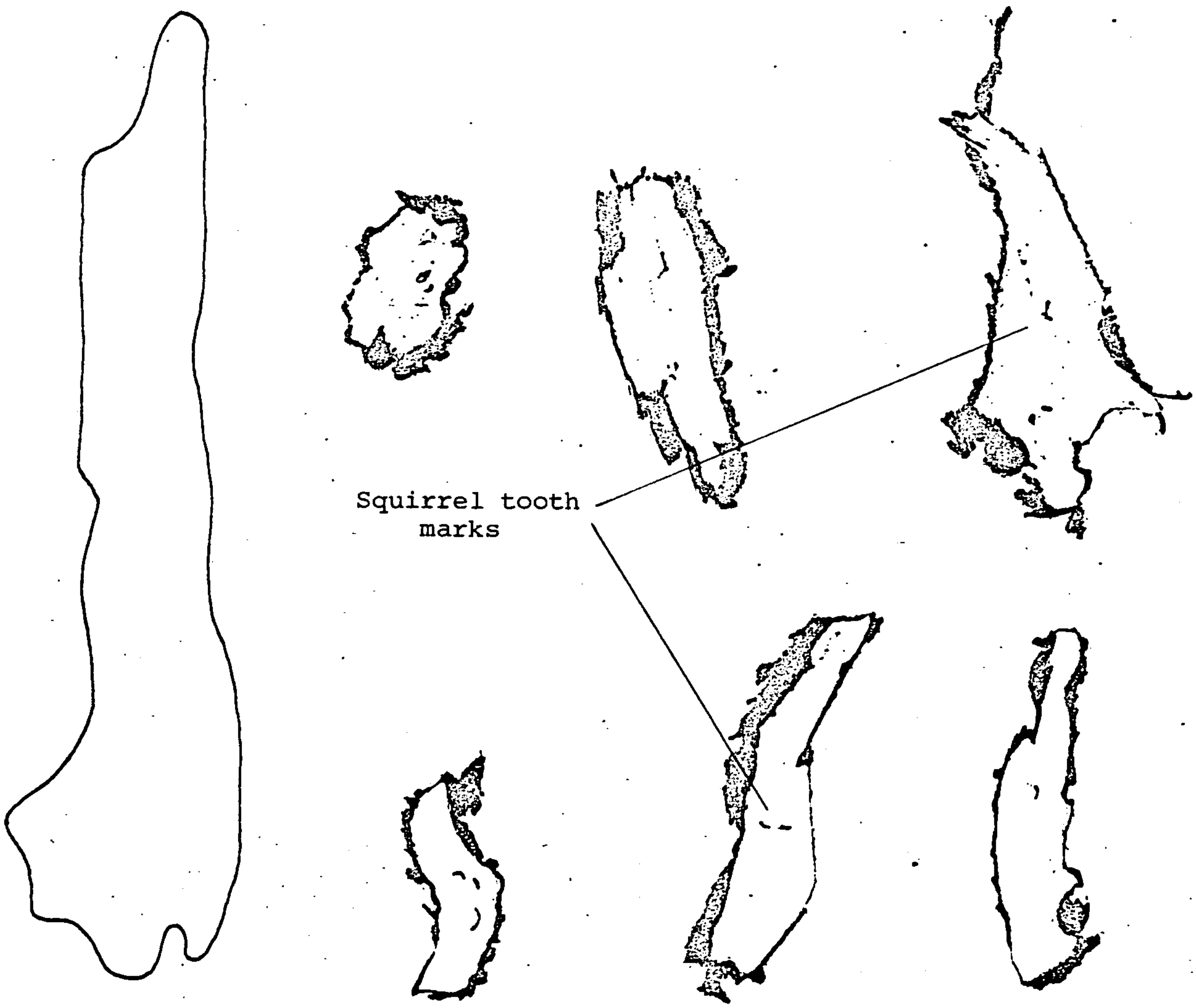


FIGURE 11 An example of the comparison of the area of one wound observed at the butt of a tree with the summed areas of the removed fragments discovered on the ground below the wound.

Plot	104
Date	1900/1-8-1979
Tree species	Sycamore No. 312
Total area of fragments	22.2 sq. cm.
Area of the wound	22.0 sq. cm.

RESULTS

RESULTS

During the course of the field work three types of damage were observed : basal stripping, stem wounds of various sizes, and less frequent incidences of upper stem or crown injuries. The stripped off patches at the butt did not always encircle the trunk of the tree and if not severe they might heal. Those at the main stem varied from "trials" to girdling. It is of interest to note that two sycamores (at the pole stage) which were found girdled in 1979 were still alive in 1980.

The rest of this chapter deals mainly with the results of detailed studies of 1980's injuries and accumulated over a period of years "damage".

5.1 Injuries and damage in relation to tree species

In 1980, six plots (5, 9, 50, 102, 104, 115) were examined every 2 or 3 days to make a complete record of all injuries sustained by the trees. With such frequent inspections there was no possibility of wounds healing between visits. These plots contained all the main species grown on the estate.

In addition to these intensively studied plots, it was decided to make an assessment of the injuries sustained over the whole estate by examination of the trees in all plots during June and July, when the peak of damage was expected to occur (see page 10). This approach seemed to be the only feasible way of making large scale assessments of the problem when time and man power are limited. This study therefore offers the opportunity to compare the results obtained by such an assessment with the detailed continuous assessment from the six plots. Any inaccuracies or biases in the former approach should thereby be made apparent.

The results from the six intensively studied plots will be discussed first (Table 4). Eight species occurred in these plots but four of them were in only small numbers. The remaining four species (Beech, Sycamore, Ash and Oak) were the four most important broadleaved species throughout the estate so the sample is a good representation. Of these four species the oaks received no injuries. Ash received no damage but had the highest percentage of injuries. All of these injuries were small "trials" and occurred early in the spring. They healed over quickly and by mid summer were no longer detectable. Both beech and sycamore received significant numbers of injuries and "damages". Beech was the more affected of the two, with 15.5 percent of the trees receiving injuries and 4.7 percent receiving damage, compared with 8.4 percent and 4.2 percent respectively for sycamore.

There were only 43 elms in the plots and 3 of these were damaged by squirrels indicating a potential susceptibility of this species. However the total sample sizes are too small for any firm statements to be made.

The data for all plots in the estate are shown in Table 5. In the case of beech, sycamore and oak there are no significant differences between these data and the data for the six intensively studied plots. This indicates that for these species at least, assessments of the damage by single inspections is a valid procedure.

In the case of ash, assessment at the peak of the season gave a significantly lower figure for the percentage of trees injured by squirrels than the continuous assessment procedure. However as stated earlier these injuries were superficial, small wounds and healed quickly. Assessment at the peak of the season would be valid for this species only if these small injuries were of no significance, for example, if they did not allow significant entry of pathogens. No measurements were made of growth rates of injured and uninjured trees so it could not be stated at this stage that the injuries were of no significance.

No injuries were recorded on the conifers and birches and only 3 percent of the horse chestnut available were injured and none damaged. 2.4 percent of the elms were damaged. The remaining three species (Lime, Norway Maple and Alder) were available in only small numbers which precludes any conclusions concerning their vulnerability to squirrel damage. However it is interesting that although only 21 Norway maple were available 23.8 percent of them were injured and 9.5 percent damaged. It would clearly be worthwhile re-examining the vulnerability of this species in an area where it is more abundant.

In conclusion we can say that beech and sycamore in that order are the most susceptible to squirrel damage. Ash, oak, horse chestnut and birch are not significantly affected. Norway maple is probably highly susceptible and should be examined further. Elm seems to be affected but a larger number of trees should be considered.

Tree species	Number examined	Number injured	Number damaged
Beech	510	79 (15.5 %)	24 (4.7 %)
Sycamore	1031	87 (8.4 %)	43 (4.2 %)
Ash	296	61 (20.6 %)	0
Oaks	615	0	
Elm	43	3	3
Birch	4	0	
Norway maple	2	0	
Conifers	48	0	

TABLE 4: Susceptibility to bark-stripping by grey squirrels of tree species in Dalmeny Estate. (Data from six plots which were regularly inspected during March to August, 1980).

Tree species	Number examined	Number injured	Number damaged
Beech	2850	485 (17 %)	201 (7.1 %)
Sycamore	3127	291 (9.3 %)	127 (4.1 %)
Ash	1459	3 (0.2 %)	1
Oaks	1637	1	0
Elm	83	2	2
Horse chestnut	131	4 (3.0 %)	0
Norway maple	21	5 (23.8 %)	2 (9.5 %)
Lime	30	1	0
Birch	112	0	
Alder	13	0	
Conifers	1404	0	

TABLE 5: Susceptibility to bark-stripping by grey squirrels of tree species at Dalmeny. (Data from 129 plots which were inspected once during the period from 10 June to 25 July, 1980).

5.2 Injuries in relation to d.b.h.

In the 6 intensively studied plots, (5, 9, 50, 102, 104, 115) the beech ranged from d.b.h. 1 - 2 cm to 17 - 18 cm with adequate numbers for analysis in the range from 3 - 4 to 11 - 12 cm. For the sycamore the total range was from d.b.h. 1 - 2 to >21 cm with adequate numbers from 1 - 2 to 13 - 14 cm. In both species the percentage of trees injured increased with increasing d.b.h. (Table 6 and Fig.12). In the beech, only 7 percent of the trees of d.b.h. 3 - 4 cm were injured whereas 31.8 percent of trees of d.b.h. 11 - 12 were injured. In the sycamore none of the trees of d.b.h. 1 - 2 cm were injured and 21.7 percent of trees of d.b.h. 13 - 14 were injured. The percentage of trees damaged in each species also increased with increasing d.b.h.

It is possible that this obvious preference for trees of larger d.b.h. could have been influenced to some extent by the size of the plots. If an individual squirrel had fewer trees to choose from it might have extended its range of preference. The six intensively studied plots varied in size but there was no apparent relationship between d.b.h. preference and size of plot. Nevertheless it was decided to re-examine d.b.h. preference with plot size and species composition factors constant. Therefore, 14 plots were selected for analysis, all of approximately equal size and of the same species composition (Table 7 and Fig.13). The same picture emerged as had done for the 6 intensively studied plots. The percentage of trees injured and damaged increased with increasing d.b.h.

Finally to establish whether this relationship holds widely throughout the estate, the data from the 134 plots were analysed in a similar way (Table 8 and Fig. 14). Once again the same picture emerged of increasing percentage of trees injured and damaged with increasing d.b.h.

Within the size range of trees examined, the squirrel therefore exhibited a very definite and widespread preference for the trees of larger d.b.h.

It has been shown earlier that beech is more susceptible to injury than sycamore (page 51). The results presented in this section are of interest in this respect as they show that all d.b.h. classes above 3 - 4 cm of beech received more injuries and damages than the equivalent d.b.h. classes of sycamore.

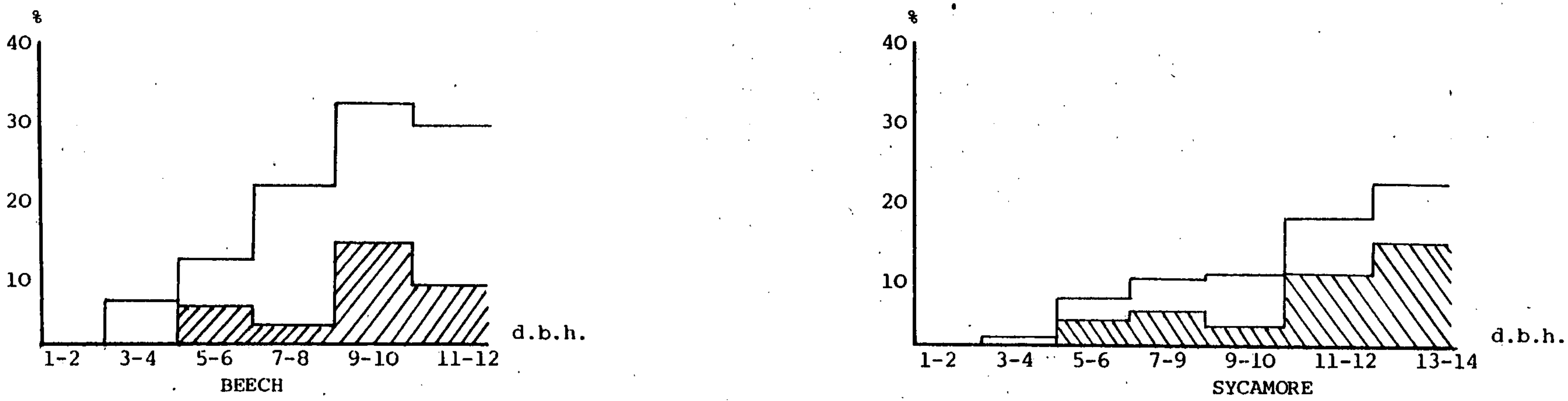
5.3 Injuries and "damage" in relation to the social position of the individual tree in the stand.

Injuries and "damage" were assessed in relation to social position for beech, sycamore and ash during the 1980 bark stripping period in plots 5, 104 and 115 (Table 9). The ash received no damage and injuries (all trials) occurred independently of the social position of the trees; suppressed individuals were subject to trials just as much as dominant individuals. For beech and sycamore however, there was a highly significant relationship between social position and the frequency of both injuries and damage. In both species suppressed trees received no damage. Subdominant beeches sustained no damage and only 1.6 percent of subdominant sycamores were damaged. In comparison dominant and codominant trees of both species received noticeably greater frequencies of both injuries and damage (Fig.15). In beech it was only dominant and co-dominant trees that sustained damage. In sycamore, 93.5 percent of the damaged trees were dominants and codominants (Fig.15).

Comparable data were obtained in 1979 but for plot 104 only (Table 10). This plot contained a total of 1190 living trees. The results were similar to those of 1980 for the 3 plots combined in that the suppressed and subdominants received few injuries and no damage. However in this case the codominants also received few injuries and damage, so that nearly all injuries sustained by the plot were on the dominant individuals.

The figures given above confirm the unquantified casual observations of previous workers that grey squirrels tend to attack the more vigorously growing trees (Shorten, 1954; Taylor, 1969; Mackinnon, 1976). The phenomenon seems to be common to some other mammals which strip bark during spring and summer such as the black bear (Lutz, 1951), the red squirrel in Britain (White, 1962) and the Richardson red squirrel in the U.S.A. (Stillinger, 1944).

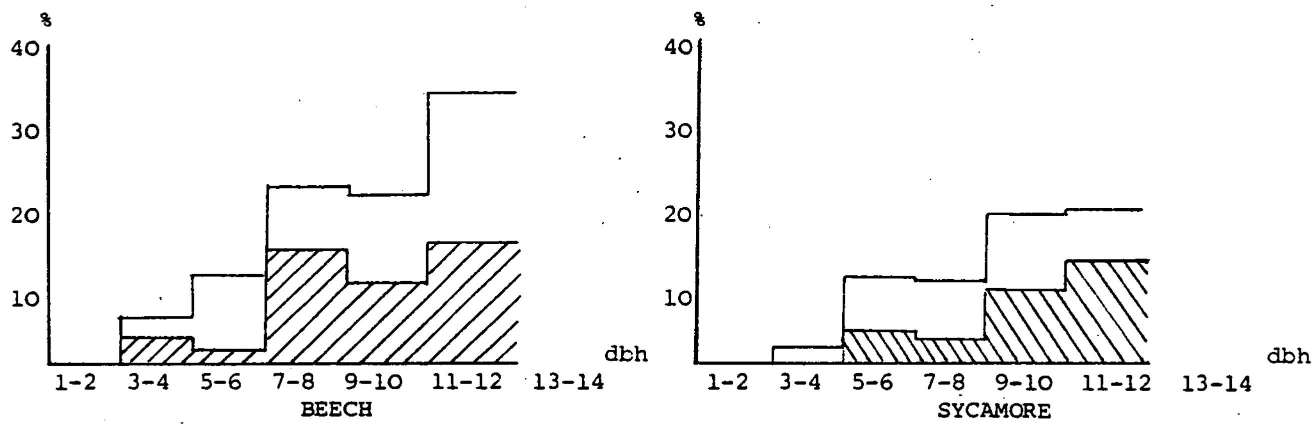
FIGURE 12 and TABLE 6



Tree Species	d.b.h. classes	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21+ more
Beech	Available	8	86	127	108	57	22	5	0	2	0	0
	Injured	0	6(7%)	16(12.6%)	23(21.3%)	19(33.3%)	7(31.8%)	5	0	1		
	"Damaged"		0	8(6.3%)	3(2.8%)	8(14%)	2(9.1%)	4	0	0		
Sycamore	Available	41	259	257	227	143	60	23	9	2	8	12
	Injured	0	3(1.2%)	16(6.2%)	21(9.3%)	14(9.8%)	11(18.3%)	5(21.7%)	2	0		
	"Damaged"		0	9(3.5%)	10(4.4%)	4(2.8%)	6(10%)	3(13%)	1	0		

Distribution of injured and "damaged" beech and sycamore according to their d.b.h.
Data from the regularly inspected six plots (5, 9, 50, 102, 104 and 115) during 1980.

FIGURE 13 and TABLE 7

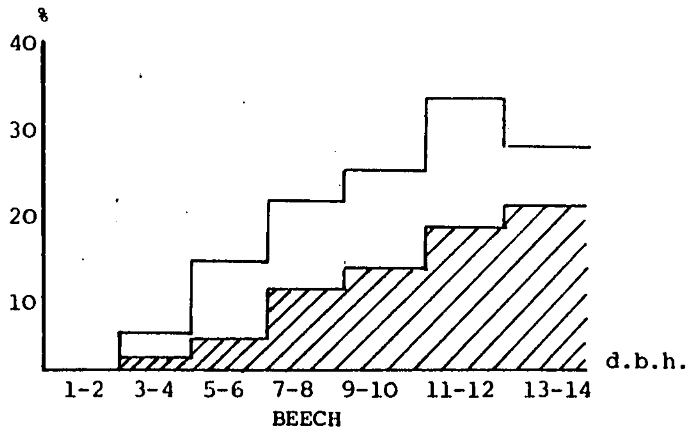


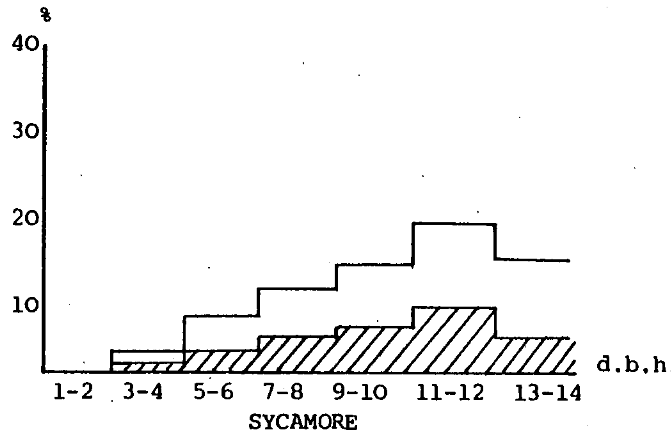
Tree Species	d.b.h. classes	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16
Beech	Available	2	52	87	76	30	20	4	3
	Injured	0	3(5.8%)	10(11.5%)	18(23.7%)	7(23.3%)	7(35%)	0	0
	"Damaged"		2(3.8%)	2(2.3%)	11(14.5%)	3(10%)	3(15%)	0	
Sycamore	Available	2	43	117	91	41	15	5	1
	Injured	0	1(2.3%)	13(11.1%)	10(11%)	8(19.5%)	3(20%)	2	0
	"Damaged"		0	5(4.3%)	3(3.3%)	4(9.8%)	2(13.3%)	0	

Distribution of injured and "damaged" beech and sycamore according to their d.b.h.

Data from 14 stands of equal size and composition inspected between 10 june and 25 July, 1980.

FIGURE 14 and TABLE 8





Tree Species	d.b.h. classes	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21+ more
Beech	Available	91	626	943	790	331	119	38	11	0	1	3
	Injured	0	28(4.5%)	131(13.9%)	174(22%)	87(26.3%)	43(36.1%)	11(28.9%)	5	0		
	"Damaged"		6(1%)	36(3.8%)	81(10.3%)	42(12.7%)	22(18.5%)	8(21.1%)	1	0		
Sycamore	Available	17	376	1050	889	493	167	64	10	7	4	4
	Injured	0	9(2.4%)	78(7.4%)	92(10.3%)	66(13.4%)	33(19.8%)	9(14.1%)	1	0	2	3
	"Damaged"		5(1.3%)	29(2.8%)	42(4.7%)	29(5.9%)	13(7.8%)	3(4.7%)	1	0	1	0

Distribution of injured and "damaged" beech and sycamore according to their d.b.h.
Data for beech taken from the 122 plots containing beech and for sycamore from 120 plots.
All data were from a single inspection carried out between 10 June and 25 July, 1980.

Tree Species	Dominant			Co-dominant			Sub-dominant			Suppressed		
	Avail.	Injur.	Damag.	Avail.	Injur.	Damag.	Avail.	Injur.	Damage	Avail.	Injur.	Damage
Beech	183	52 (28.4%)	18 (9.8%)	17	5 (29.4%)	2 (11.8%)	90	10 (11.0%)	0	112	5 (4.5%)	0
Sycamore	386	40 (10.3%)	23 (6.0%)	108	16 (14.8%)	6 (5.6%)	122	7 (5.7%)	2 (1.6%)	175	0	0
Ash	140	23 (16.4%)	0	15	2 (13.3%)	0	52	10 (19.2%)	0	50	7 (14.0%)	0
Oak	120	0	0	58	0	0	53	0	0	90	0	0

TABLE 9 : Injuries and "damage" in relation to the social position of the individual tree in the stand. Data from regular inspections of the plots 5, 104 and 115 during March to August, 1980.

Beech: Comparing dominants and co-dominants combined, with sub-dominants and suppressed combined.

Injuries $x^2 = 30.4$, $p<0.001$

"Damage" $x^2 = 21.3$, $p<0.001$

Sycamore: Comparing dominants and co-dominants combined, with sub-dominants and suppressed combined.

Injuries $x^2 = 20.3$, $p<0.001$

"Damage" $x^2 = 13.1$, $p<0.001$

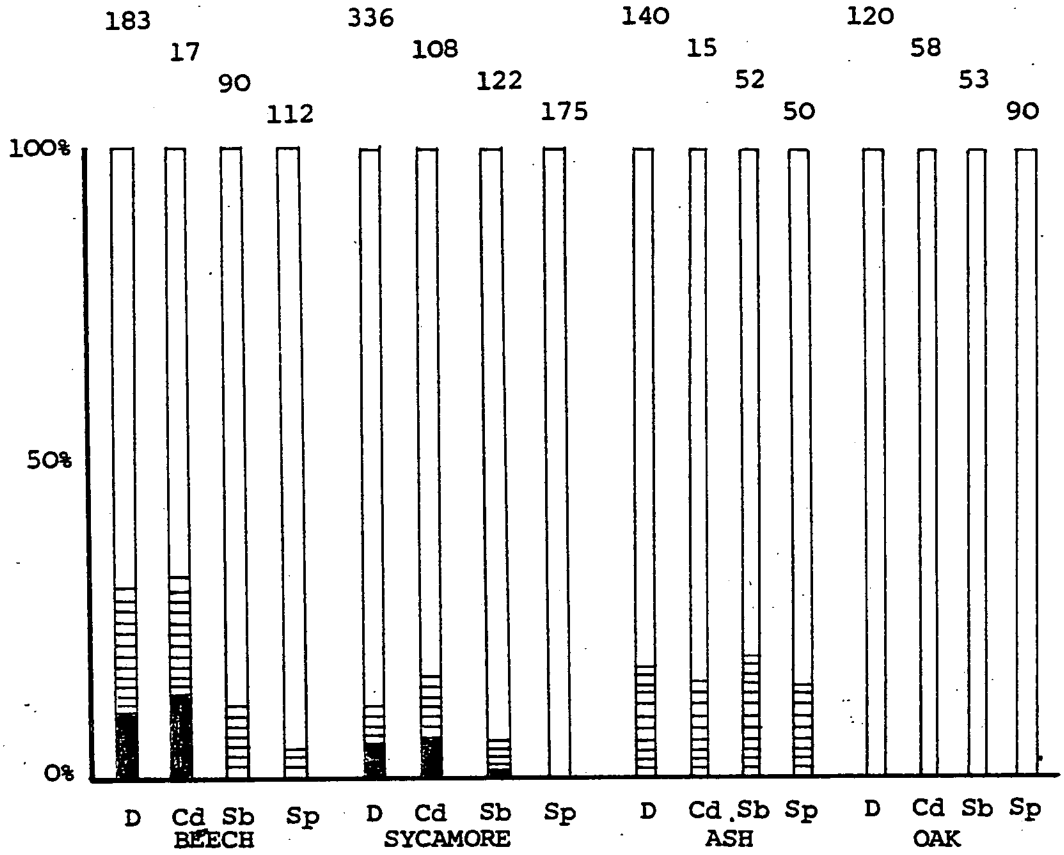


FIGURE 15: Percentage of injuries in relation to social position of the individual tree in the stand.

The information provided is based upon data collected during March to August, 1980.

Sample sizes are given along the tops of the bars.

☐	Not injured	D :	Dominant trees
▤	"Trials"	Cd:	Co-dominant
■	"Damages"	Sb:	Sub-dominant
		Sp:	Suppressed

Tree Species	Dominant			Co-dominant			Sub-dominant			Suppressed		
	Avail.	Injur.	Damag.	Avail.	Injur.	Damag.	Avail.	Injur.	Damag.	Avail.	Injur.	Damag.
Beech	168	14 (8.3%)	13 (7.7%)	3	1	1	71	4 (5.6%)	0	95	1	0
Sycamore	302	51 (16.9%)	50 (16.6%)	26	0	0	56	1	0	121	0	0
Ash	111	3 (2.7%)	0	8	0	0	44	1	0	42	0	0
Oak	68	0	0	5	0	0	14	0	0	56	0	0

TABLE 10: Injuries and "damage" in relation to the social position of the individual tree in the stand.

Data from plot 104 which was regularly inspected between mid-May and late September, 1979.

5.4 The location of injuries on the tree

Two separate aspects of this problem were considered. Firstly, it was important to know whether injuries occurred on the butt (i.e. up to 30 cm from ground level) or higher, on the stem. Damage to the butt (unless it is very extensive), is unlikely to be of serious concern to the forester whereas stem damage could reduce the value of the timber.

In addition to this, records were kept of whether new injuries occurred at sites that had been injured previously and were in the process of healing (*callus*) or whether they occurred at completely new sites.

The data for 1980 derived from two sources. Six plots (5,9, 50, 102, 104, 115) were observed at intervals of about 2 to 3 days throughout the relevant time period. In these plots all new wounds could therefore be detected very shortly after they occurred and the data are a complete record of injuries in the plots.

In addition to this, all the remaining 154 plots were examined during June and July for the total season's cumulated wounds. It is possible that some small injuries (trials) could have healed completely between their occurrence (early in the season) and the time the observations were made. However, such injuries would not have been of great significance and a comparison of the data from the two sources (see below) does not show substantial discrepancies.

As was described in the methods section (page 37) injuries were assessed by examining all of the trees in plots of less than 0.07 ha and by taking random samples from stands greater than this. In the specific case of examining trees for the location of their injuries, in these latter stands, a constant look out was kept for injured trees whilst moving from one randomly selected tree to the next. This was done to ensure large sample sizes and a total of 57 injured trees (29 sycamore and 28 beech) were added in this way.

Most of the injuries to both beech and sycamore occurred at the butt of the trees (Tables 11 and 13). The same picture emerged from the two sources of information (continuous and cumulative recording). However, there was a noticeable difference between the species. Beech received a much lower percentage of its injuries to the stem (15.3 %) than did sycamore (28.1 %) (Table 11).

The pattern for damage was very similar. Both species received a much greater incidence of damage to the butt than to the stem and the percentage of damage to the stem was significantly greater in sycamore than in beech (Table 12).

In both beech and sycamore most of the new injuries occurred at sites which had already been injured and had developed callus tissue (Table 14). For beech only 13.4 % of the new injuries occurred to previously undamaged sites and for sycamore the figure was only 10.4 %.

Tree Species	Total Injuries	Injuries to BUTT			Injuries to STEM		
		Total	Callus	Bark	Total	Callus	Bark
Beech	890	754(84.7%)	668(88.6%)	86(11.4%)	136(15.3%)	103(75.7%)	33(24.3%)
Sycamore	491	353(71.9%)	330(93.5%)	23(6.5%)	138(28.1%)	110(79.7%)	28(20.3%)

TABLE 11: Incidence and relative frequency of injuries on butt and stem of beech and sycamore.

Data for beech taken from the 92 plots containing beech and for sycamore from 94 plots.

All data were from a single inspection carried out between 10 jUne and 25 July, 1980.

Tree Species	Total Injuries	"Damages" to BUTT			"Damages" to STEM		
		Total	Callus	Bark	Total	Callus	Bark
Beech	294	255(86.7%)	235(92.2%)	20(7.8%)	39(13.3%)	27(69.2%)	12(30.8%)
Sycamore	215	142(66%)	137(96.5%)	5(3.5%)	73(34%)	59(80.8%)	14(19.2%)

TABLE 12: Incidence and relative frequency of "damages" on buttand stem of beech and sycamore.

Data for beech taken from 92 plots containing beech and for sycamore from 94 plots.

All data were from a single inspection carried out between 10 June and 25 July, 1980.

Tree Species	Total Injuries	Injuries to BUTT			Injuries to STEM		
		Total	Callus	Bark	Total	Callus	Bark
Beech	158	155(98.1%)	137(88.4%)	18(11.6%)	3(1.9%)	2	1
Sycamore	118	98(83%)	89(90.8%)	9(9.2%)	20(17%)	17(85%)	3(15%)
Ash	46	46(100%)	40(87%)	6(13%)			

TABLE 13: Incidence and relative frequency of injuries on butt and stem of beech, sycamore and ash trees.

(Data from six plots which were regularly inspected between March to August, 1980).

Tree Species	Total Injuries	Callus	Bark
Beech	890	771(86.6%)	119(13.4%)
Sycamore	491	440(89.6%)	51(10.4%)

TABLE 14: Incidence and relative frequency of injuries started on callus or bark of beech and sycamore.
Data for beech taken from the 92 plots containing beech and for sycamore from 94 plots.
All data were from a single inspection carried out between 10 June and 25 July, 1980.

5.5 Wound Size and Orientation

During 1980, 280 wounds classified as "damage" wounds (see page 64) were inspected on beech and 196 on sycamore.

On beech, 238 (85%) were on the butts of the trees. Their sizes ranged from 7 x 1.5 cm to 50 x 15 cm (750 sq. cm). Forty two (42) wounds exceeded 100 sq. cm. but the majority were below this size (Table 15). In general wounds on the butt were more long than broad. The average dimensions for the wounds of less than 100 sq. cm. were :

Length 12.7 ± 6.4 cm (1 SD)

Breadth 3.4 ± 1.5 cm (1 SD)

Forty two (42) of the wounds on beech occurred on the stem. Their dimensions ranged from 4 x 3 cm (12 sq. cm.) up to 15 x 25 (375 sq. cm). Nine (9) exceeded 100 sq. cm. Again the stem wounds were longer than broad. The average dimensions of those less than 100 sq. cm. were :

Length 11.5 ± 5.5 cm (1 SD)

Breadth 3.4 ± 1.3 cm (1 SD)

There was no significant difference in the size of wounds between butt and stem.

In sycamore, 129 (65.8%) of the 196 "damage" wounds occurred on the butt (Table 15). Their dimensions ranged from 7 x 1.5 cm (10.5 sq. cm.) to 98 x 6 cm (588 sq. cm.). Only 11 wounds exceeded 100 sq. cm. The average dimensions for wounds less than 100 sq. cm. were :

Length 14 ± 7.4 cm (1 SD)

Breadth 2.5 ± 1.1 cm (1 SD)

Sixty seven (67) of the wounds occurred on the stem and their sizes ranged from 6 x 2 cm (12 sq. cm) to 50 x 25 cm (1250 sq. cm.). Only

Wound size in sq. cm. / Wounds on	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-125	126-150	151-175	176-200	201+ more	Total
Beech butt	56	37	33	11	18	6	14	6	15	17	6	2	7	10	238
Beech stem	9	10	2	3	2	-	2	2	3	3	2	-	-	4	42
Sycamore butt	43	31	15	10	8	-	7	3	1	3	4	-	1	3	129
Sycamore stem	13	15	4	6	3	1	4	4	4	4	-	2	1	6	67

TABLE 15 : The size of wounds on beech and sycamore.

The data for butt and stem wounds are given separately.

Data for 1980 (March to August).

13 wounds exceeded 100 sq. cm. The average dimensions of wounds less than 100 sq. cm. were :

Length 17.5 ± 9.9 cm (1 SD)

Breadth 3 ± 2.7 cm (1 SD)

In plots 5, 102 and 104 records were kept of the orientation of the "damage" on the tree trunk (stem and butt combined). It seemed possible, for a variety of reasons (shelter from wind, dryness of bark, e.g.), that the squirrels might have had a preference for particular orientations. However, no such preference was found : wounds occurred at all points round the circumference of the tree trunk (Fig.16).

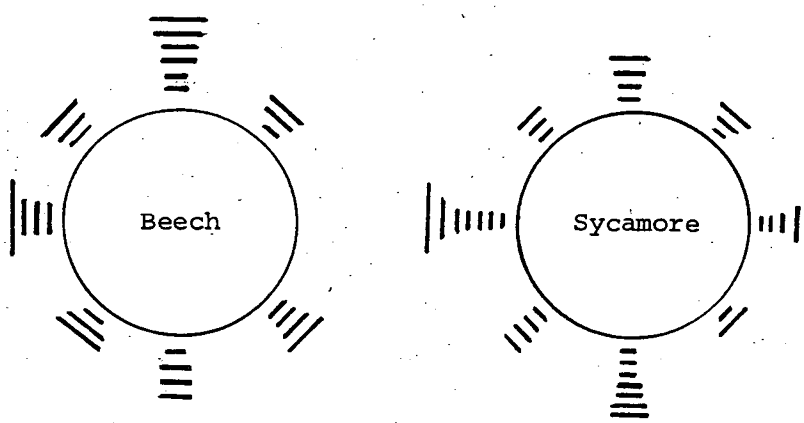


FIGURE 16: Orientation of "damage" on beech and sycamore. Data from plots 5, 102 and 104 which were regularly inspected between March to August, 1980. Each bar on the figure represents a separate instance of damage. The length of the bar signifies the width of the wound on a scale of 1:10.

5.6 Timing of injuries and damage

The timing of injuries and damage for 1980 was examined in detail by analysing the data from the inspections of trees in plots 5, 104 and 115. In these plots there were a total of 406 beech, 799 sycamore, 266 ash and 319 oak. No injuries were recorded on oak and only trials were observed on ash. Therefore only beech and sycamore will be considered.

The first injuries were noted during the first 10 days of May (Figure 19). These were all on the beech with none on sycamore. These first injuries to beech were all very small "trials" of less than 2 square cm. During the second 10 days of May again only beech received injuries and again these were "trials". The first injuries to sycamore occurred in the fourth week of May. Injuries to both beech and sycamore were plotted as cumulative percentages (Figure 18). This shows clearly that the injuries to beech started approximately 20 days earlier than those to sycamore and that injuries to beech were ahead of those to sycamore until the beginning of July. By the middle of June 49.5 percent of all the injuries received by beech had already occurred whereas at that time sycamore had only received 16 percent of its injuries. A peak in injuries to both beech and sycamore was evident in the first 10 days of July (Fig. 19). The last injuries to beech were received in mid-August and those to sycamore in the first 10 days of August. The whole season for injuries therefore lasted for about 15 weeks in beech and 11 weeks in sycamore.

"Damage" to both beech and sycamore was first recorded in the last 10 days of May (Fig. 19). The peak of "damage" to beech occurred in early July and in sycamore it occurred in late June. The last 10 days of June and the first 10 days of July was the most severe period for "damage" to species. Almost 50 percent of all the "damage" recorded to beech occurred at this time and 70 percent of all the "damage" to sycamore.

In 1980 records were also kept of the seasonal pattern of flushing of all the trees in the three plots (Fig. 17). Each tree in the plot was examined at intervals of about 10 days. At each inspection it was noted whether the leaf buds were still closed or whether they were opening or already fully opened. The first flushing of beech was recorded in the last 10 days of April and by the first 10 days of May 97 percent of the beech had their buds opened. Sycamore did not start flushing until the first 10 days of May and about 97 percent of them had flushed by the middle of May. Sycamore was therefore about 10 days behind beech in flushing. Ash and oak opened their buds at approximately the same time as sycamore. There was therefore a strong correlation between the seasonal pattern of injuries and the pattern of flushing. Beech flushed ahead of sycamore and injuries to beech started earlier than injuries to sycamore.

Records from plots 9,102 and 104 for 1979 showed that timing of injuries and "damage" followed a pattern similar to 1980, (i.e. beech was injured earlier than sycamore). The first injuries started as "trials" to both beech and sycamore trees.

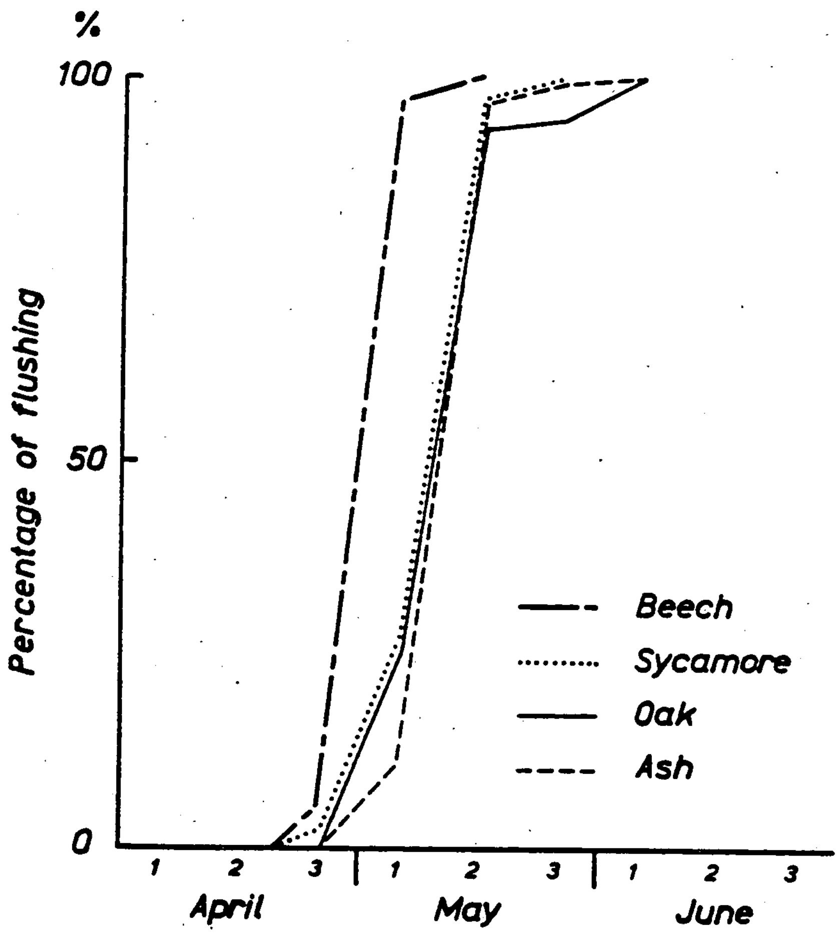


FIGURE 17: Cumulative Percentage of buds opened for each tree species examined at 10 day intervals

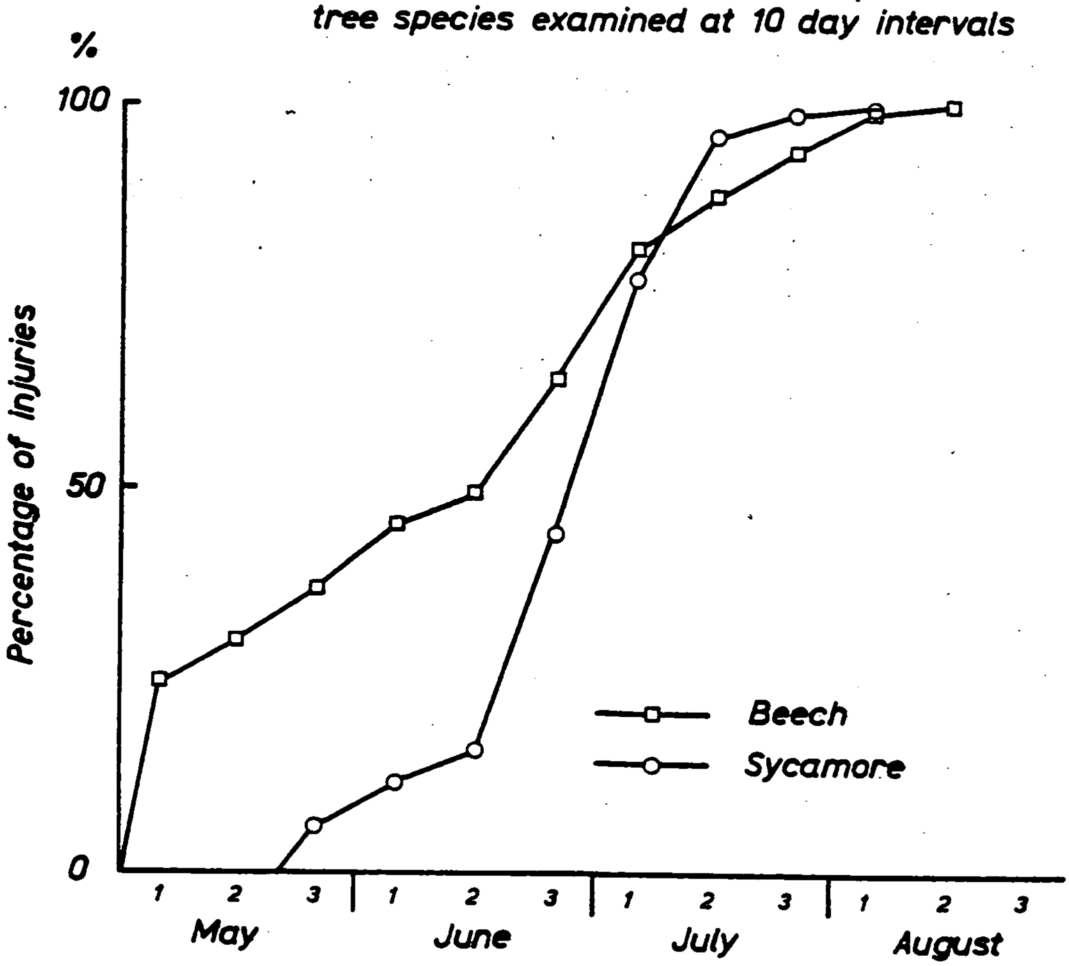


FIGURE 18: Cumulative Percentage of injuries to Beech and Sycamore examined at 10 day intervals

Injuries to beech appeared in the second week of June, reached a peak during the first week of July and ceased in early August, while the peak of "damage" occurred at the first week of July. Injuries to sycamore were noticed in the fourth week of June with a peak during the third week of July, and ceased in mid August. The peak of "damage" to sycamore was recorded during the third week of July.

The delay observed in the starting date of injuries and "damage" might be due to the severe winter of 1978-79 which caused a delay in the onset of flushing.

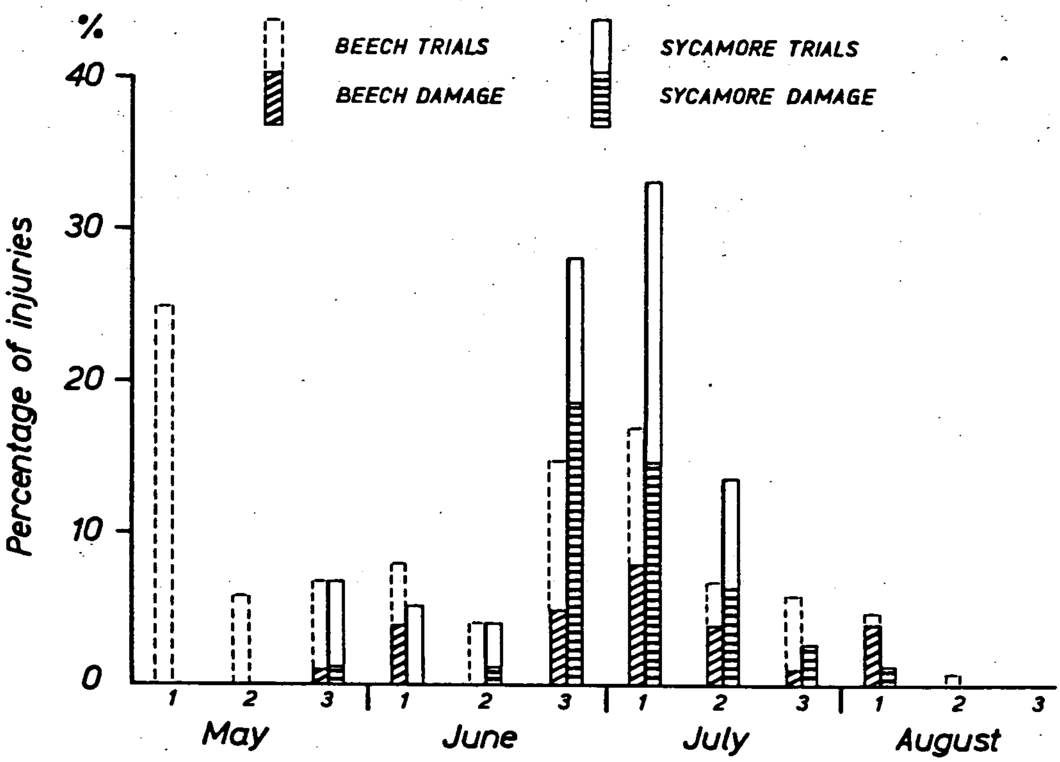


FIGURE 19: Distribution of injuries (i.e. trials and damage) for Beech and Sycamore during the 1980 bark-stripping period

5.7 The severity and extent of the damage

So far we have described the occurrence of new injuries to individual trees. This has provided a more precise insight into the nature of bark-stripping than was previously available. However in practical forestry the other important aspect is the accumulation of injuries over a period of years and the percentage of the trees in the plots that are affected. It is important to have some measure of the severity of such accumulated damage both to the individual trees and to the plots as management units.

The method of assessing the severity of the damage was described on page 43. Damage to individual trees was assessed as light, moderate or severe depending on the circumference of the trunk that was affected. By examining samples of trees in each plot (and in the case of small plots, all trees) the extent of the damage within the plot was assessed.

The plots which contained either beech or sycamore or both showed a complete range of damage, from no damage at all to 100 percent of the trees damaged (Fig. 20). The plots of beech tended to be evenly spread over this range with just as many plots having few trees damaged as having most trees damaged. Sycamore on the other hand showed a markedly different pattern; most plots of sycamore had most of the trees with damage (Fig.20). The result of several years' accumulated damage at Dalmeny was obviously highly significant. For beech 57 percent of the plots in the estate had more than 50 percent of the trees in them damaged. For sycamore the picture was even worse with 87.7 percent of the plots having more than 50 percent of the trees damaged.

The most important information concerns the trees that had received damage at a severe level. Again there were large differences between beech and sycamore. In both there was a complete range of plots from those with few trees severely damaged to those with 100 percent of the trees severely damaged. However most of the plots of beech had a low percentage of the trees severely affected (e.g. 37 percent of the plots had 10 percent or less severely damaged) whereas in sycamore there was an even distribution of plots over the whole range from 0 to 100 percent severely affected (Fig. 21). When beech and sycamore are compared in the same plots, it is clear that in nearly every plot a much higher percentage of the sycamore had been heavily damaged than the beech (Fig. 22).

The relationships between percentage of trees severely damaged in each plot, the mean d.b.h. of the plot and the size of the plot were examined. There was no correlation between mean d.b.h. and the percentage of trees severely damaged (Fig. 23). Also there was no overall correlation between plot size and the percentage of trees severely damaged (Fig. 24). However, there might nevertheless be some relationship between the two. In both beech and sycamore, the small plots received all levels of severe damage from 0 to 100 percent. However the largest plots had much lower percentages of severe damage. Unfortunately there were very few large plots so no firm conclusion can be reached but it would be worthwhile considering damage in relation to plot size in an area where more large plots were available.

Data for the levels of damage in all the individual plots examined are given in Appendix V.

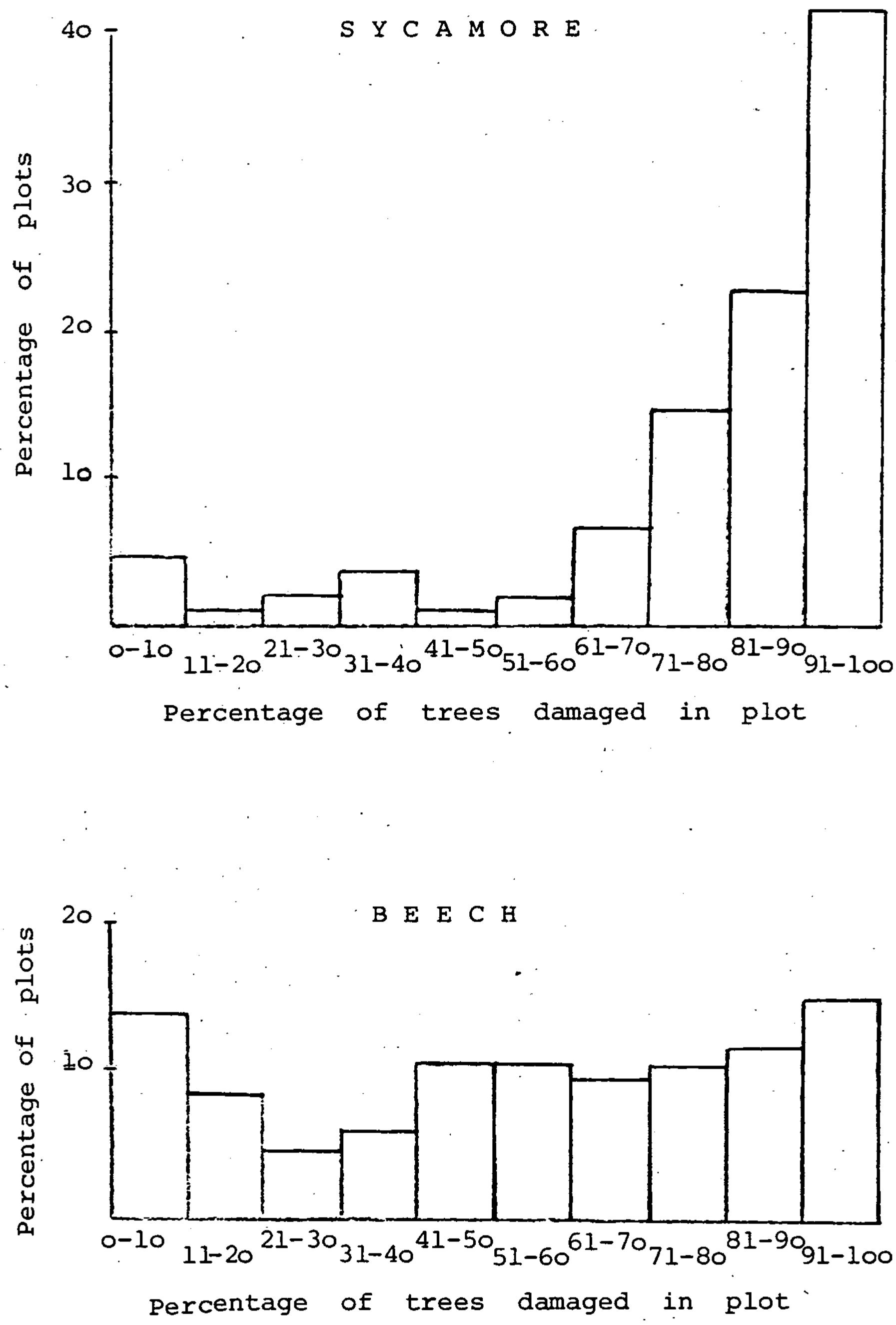
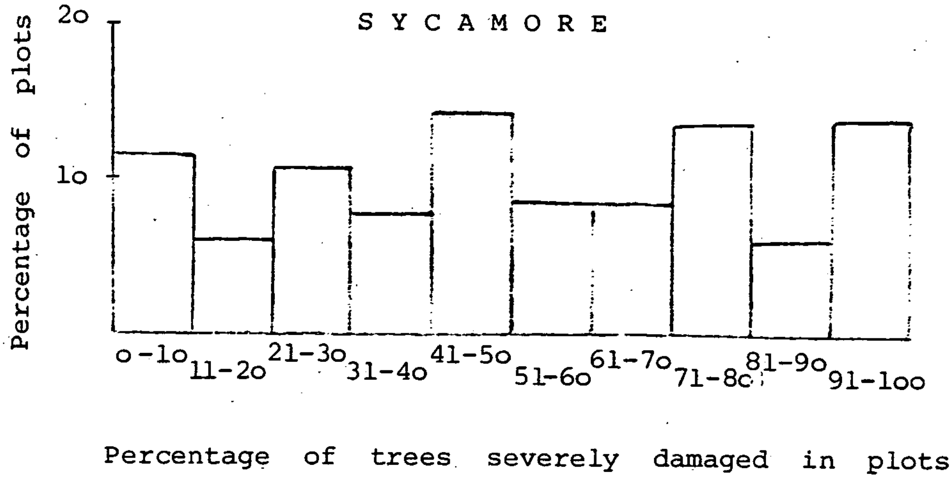


FIGURE 20 The frequency distribution of damaged trees in the plots of beech and sycamore.



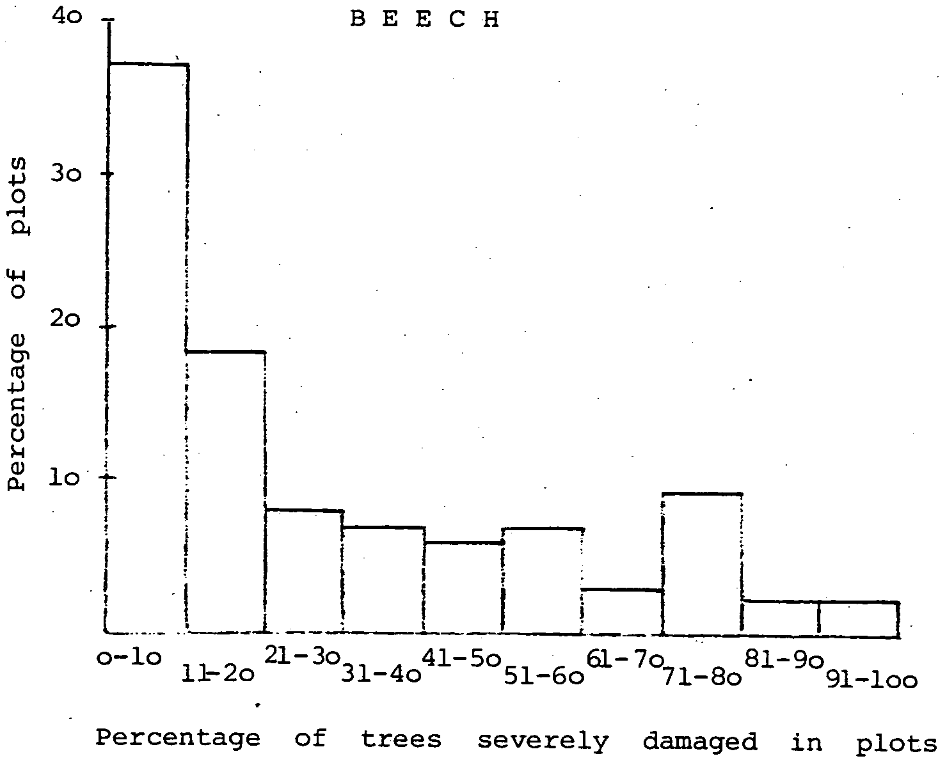


FIGURE 21 The frequency distribution of severely damaged trees in the plots of beech and sycamore

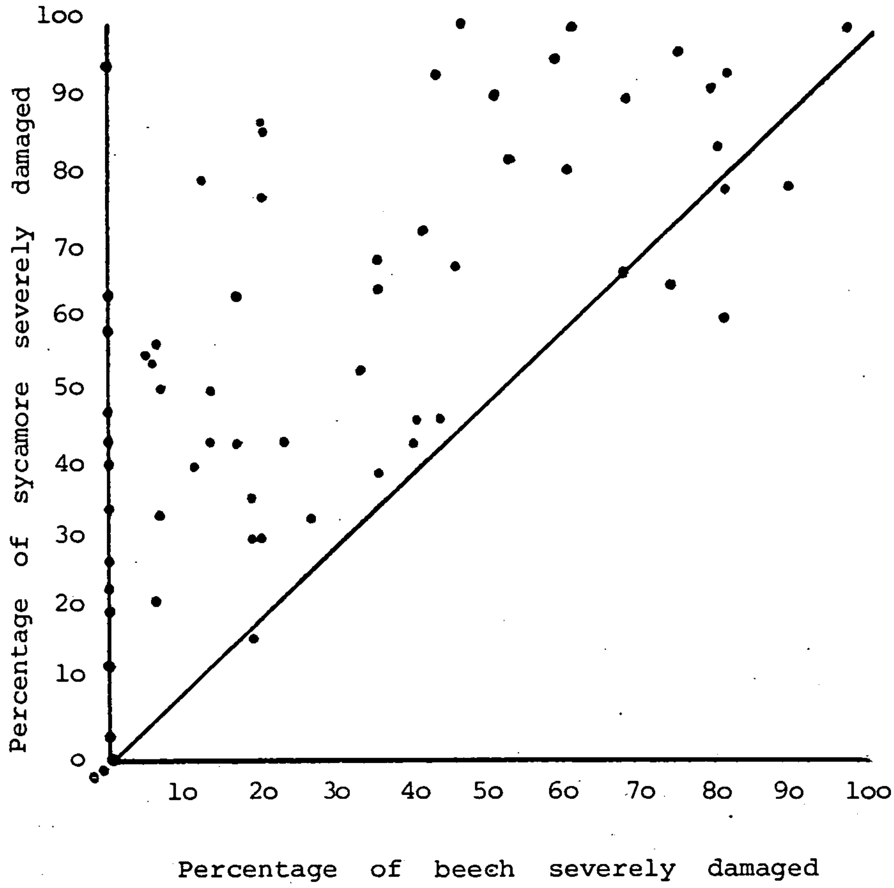


FIGURE 22 The relationship between the percentage of sycamore severely damaged and the percentage of beech severely damaged in the same plots.
Each point represents a separate plot.
Nearly all the points lie above the line showing that in most plots a higher percentage of the sycamore were severely damaged.

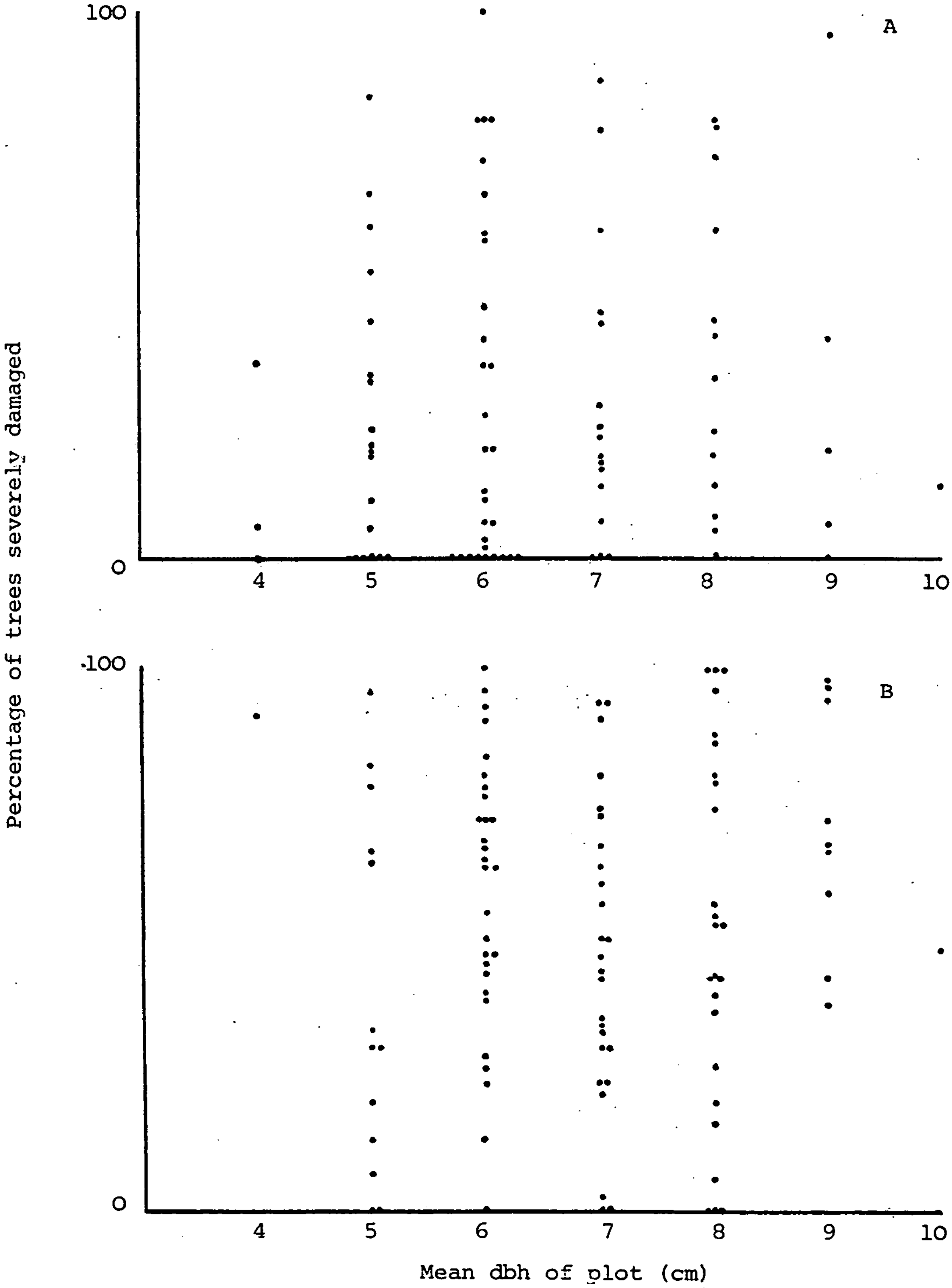


FIGURE 23: The relationship between mean dbh of the plot and the percentage of severely damaged beech and sycamore. Each point represents a separate plot.

A = Beech B = Sycamore

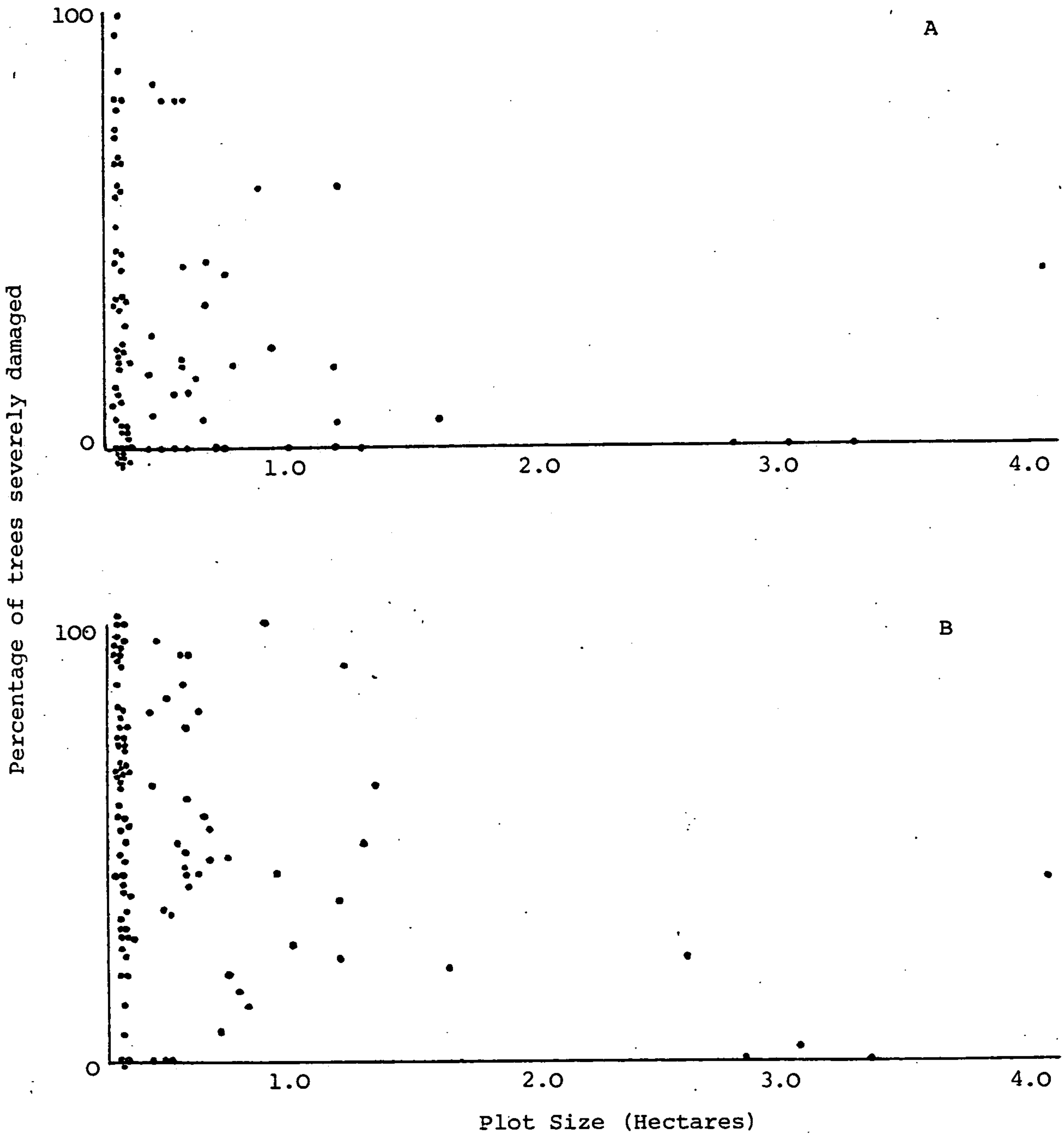


FIGURE 24: The relationship between plot size and the percentage of severely damaged beech and sycamore. Each point refers to a separate plot

A = Beech B = Sycamore

D I S C U S S I O N

The objective of this thesis was to examine the implications of bark-stripping by grey squirrels for the forester and to suggest ways in which the problem can be minimised. It was not a primary objective of the study to answer the question "Why do squirrels strip bark ?". Nevertheless this question is obviously central to the problem and a clear answer to it would undoubtedly assist in management. Therefore before considering the question of management it is valuable to examine the underlying causes for bark-stripping and to consider how the new evidence from this study contributes to a better understanding of the problem.

A total of four different main causes have been advanced by a variety of workers :

1. To wear down the incisors
2. To obtain nesting material
3. Redirected aggression during social encounters
4. To obtain food.

A number of researchers (Burgess 1954; Seymour 1961; Taylor 1969; Mackinnon 1976) have suggested that more than one of the causes operates simultaneously. Below, each of the above suggestions will be examined in the light of the present study and other published, information.

1. To wear down the incisors

No evidence has been found to support this hypothesis and there is a number of factors that strongly suggest that it is not valid. Firstly, although the grey squirrel is mainly vegetarian, in a wide sense, its foods cannot be regarded as soft (see page 23).

Secondly, it was demonstrated that the species most attacked were soft-barked (beech and sycamore). Hard-barked ones such as oak were avoided. If the animal only wanted to wear down incisors it would surely have selected the hard-barked species. Thirdly, this hypothesis does not account for the very restricted time period during which stripping occurs. In particular there should have been two peaks of bark-stripping associated with the two peaks of population after the two breeding periods.

2. To obtain nesting material

Davidson and Adams (1973 and 1975) found that canopy nests contained substantial quantities of bark and suggested that during the breeding season there must be a regular demand for bark strips to line their dreys. They observed that bark taken for such purposes was stripped off in lengths of from 15 to 60 cm and only 2.5 to 5 cm width. Mackinnon (1976) also found strips of bark lining dreys but found that most of these were from oak, lime and elder. This was in areas where there were also beech and sycamore available. She also observed that captive and wild animals took this bark by stripping thin branches. Therefore, both the species of tree involved and the shape of the strips removed do not fit with the observations of bark-stripping damage at Dalmeny. In addition the observations made of bark fragments found below wounds at Dalmeny (see page) showed that none of the bark pieces had been carried off. Dreys are reconstructed and relined during late October and November (Shorten 1954). Yet, no bark stripping was recorded on the study trees at Dalmeny at this time.

All the above evidence suggests that the type of damage which we are concerned is not caused by removal of bark for nest lining.

3. Aggressive interactions between animals

Much emphasis has been placed on the hypothesis that bark stripping occurs during agonistic encounters between squirrels. It has been suggested that the stripping is a form of redirected aggression during such encounters. Taylor (1969) observed that serious bark damage was most often caused by subdominant animals. He noted that the main period of serious damage coincided with a period of heightened social activity in the squirrel population when adult resident males and females chased the young born in the spring out of the main centres of the population. Such evicted animals dispersed to stands of younger trees which had few resident adults. These stands were regarded by Taylor as suboptimal habitat because food supplies such as seeds were in short supply there. It was in these younger stands that Taylor observed most of the serious damage. He suggested that the damage was caused by the young animals during aggressive encounters as they first tried to establish themselves in these new areas. Taylor proposed that eating of the exposed tissue was a secondary activity and redirected aggression the primary activity. Mackinnon (1976), suggested that both food requirements at a time of food shortage and aggressive interactions between young animals were the cause of bark stripping but did not specify whether these operated independently of each other or whether one followed after the other.

In contrast to the above, Davidson and Adams (1973) found that adult males were also included in bark stripping during the breeding season although they stated that only relatively small pieces were removed by them.

A number of the findings of the present study raise important questions regarding the significance of redirected aggression as the causation of bark-stripping. Firstly it is known that the grey squirrel has two breeding seasons each year. There will therefore be two periods each year when there are large numbers of young subdominant animals in the population. The above authors refer to the expulsion of young in the spring leading to damage in May and June. Why is there no second peak of damage later in the year ? One would expect the second broods to be forced to disperse in a similar manner to the first broods and one would therefore expect a second peak of damage if redirected aggression were the cause of damage. Such a second peak does not occur. It is perhaps significant that the time at which a second peak might be expected is not a time of food shortage.

Secondly, if redirected aggression were the primary cause of bark stripping why should the relationship between the time of flushing in the different species and the time of damage to them exist ? It seems highly unlikely that agonistic encounters early in the season should only occur when the squirrels happened to be on beech. One would expect a random distribution of damage between species.

Also why should damage occur mostly to the vigorously growing dominant trees ? It is possible that the squirrels spent most of their time in such trees because of their size so that agonistic encounters occurred mostly when the animals were on these trees. There is no evidence one way or the other on this but it certainly needs to be investigated.

The finding that damage occurred mostly on callous tissue seems incompatable with the idea of redirected aggression as a primary cause. One would expect the redirected aggression to occur at the place where the interactions between the animals occurred. Did these interactions only happen to occur when the animal was near to a piece of callous tissue ? It seems unlikely. It also seems unlikely that the animal would search around for a piece of callous tissue before redirecting its aggression.

All these findings point to the possibility that redirection of aggression might not be the primary cause of bark stripping.

4. To obtain food

Bark-stripping is not a phenomenon that is restricted to grey squirrels; it has been recorded from a wide range of mammals in a variety of habitats. It is therefore instructive to consider first the evidence available on the reasons for bark-stripping in these other species.

Red deer (*Cervus elaphus* L.) cause considerable damage, mainly in conifer plantations, by bark-stripping. The damage reaches a peak in late winter. This is the time when the animals' reserve of fat is at its lowest and when the quantity and quality of food available is also at its lowest (Mitchel, *et al* 1977). A number of other authors have suggested that red deer utilize bark and/or the combial tissue underneath it as a source of food at times of shortage of the prefered foods (Ueckerman, 1960; Rijcken, 1965; Ahlen, 1965).

Black bear (*Euarctos americanus* Pallus) in North America remove bark in the spring and feed on the exposed sapwood. They show a preference for species with high sugar levels and low ash components (Radwan, 1969).

Consumption of bark by the european rabbit (*Oryctolagus cuniculus* L.) is a well known phenomenon. Most of this stripping occurs in winter during deep snow cover when other foods are buried (Ognev, 1947; Boyce, J., I.T.E. personal communication).

Bark-stripping by the red squirrel (*Sciurus vulgaris* L.) has been studied (Tittensor 1975). This occurs during May and June, the period when the normal primary food of pine seeds is not available. Tittensor concluded that the squirrels utilise the vascular tissue under the bark as a primary food at this time along with buds, shoots and pollen.

All of the evidence in this diversity of species indicates that bark-stripping occurs to obtain food at times when the prefered foods are unavailable.

A number of authors have suggested that grey squirrels strip bark to obtain food (Shorten, 1954, 1957; Taylor, 1969; Davidson and Adams, 1973; Mackinnon, 1976) but the evidence is not yet conclusive.

Firstly it is important to point out that there is no evidence that grey squirrels deliberately consume the bark itself. In stomach analyses only small fragments of bark have been found and attributable to accidental ingestion during stripping (Mackinnon, 1976). Also in this study the examination of the bark fragments under wounds showed that none had been eaten. Therefore the discussion involves the consumption of the tissue under the bark rather than the bark itself (see Fig. 25 and Plate 2).

The primary food of the grey squirrel has been found to be beech mast, acorns, hazel nuts and samaras, available from about July/August to the end of March (Taylor, 1969; Mackinnon, 1976). The timing of damage by bark stripping (May to July) therefore coincides with the period of shortage of the main food supply. During the period the animals have been shown, by stomach analysis, to eat flowers, shoots, fungi, insects, plant fibres and cambial tissue (Mackinnon, 1976). A similar pattern has been shown in the U.S.A. (Nixon, *et al.*, 1968).

A number of the findings of this study also support the hypothesis that feeding is the primary motivation for bark-stripping. Comparing beech and sycamore there was a correlation between the timing of damage and the timing of leaf development. Beech opened its leaves first and was also attacked first (see Fig. 18). There was a time gap between the opening of the leaves and the appearance of "damage". These observations are consistent with the idea that damage occurred with the start of carbohydrate manufactured by the trees.

Dominant and co-dominant trees received nearly all the damage and subdominants and suppressed trees received little damage (see Fig 15). Again this could be related to the level of carbohydrate manufacture. Lastly most of the new injuries started on callous tissue. Callous tissue is soft and more easily removed but more importantly callous is a healing tissue and is known to have high levels of nutrients (

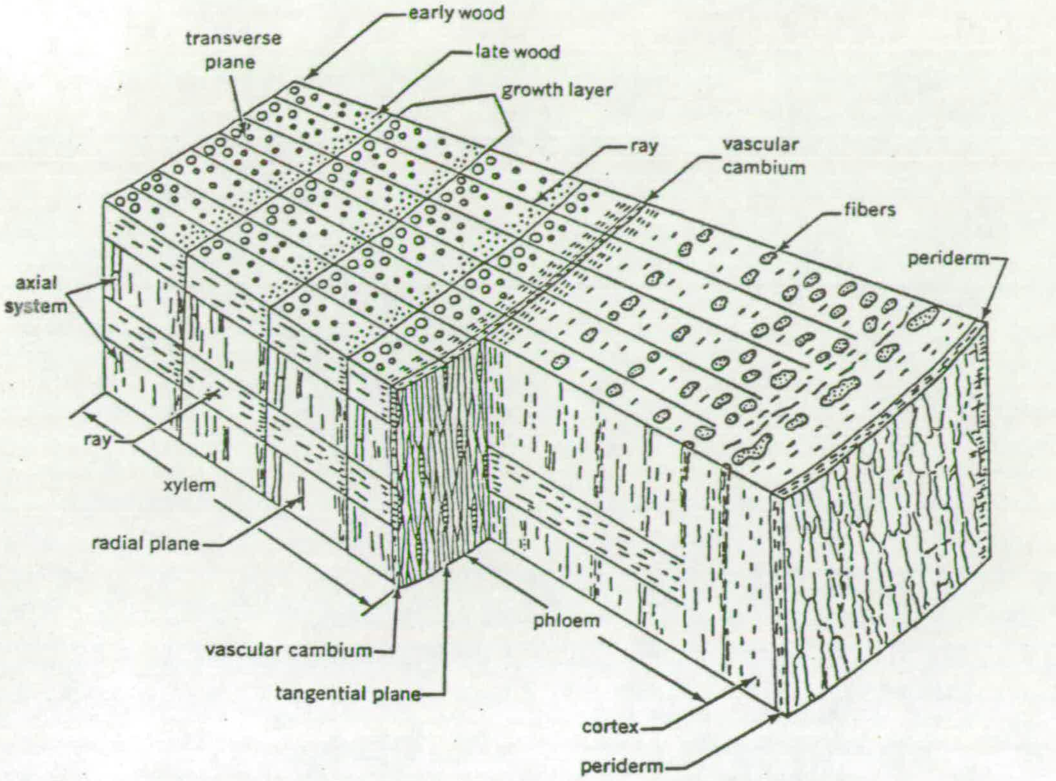


FIGURE 25: Basic features of secondary vascular tissues and their spatial relation to each other.

Source: Esau, K. (1977). Anatomy of Seed Plants.

PLATE 2: Beech wound showing tissues removed by grey squirrel. The areas showing white have had the phloem removed. The light tan coloured areas are where the phloem remains.

None of these is conclusive in itself and should all be tested further, but they support the feeding hypothesis. It is also interesting to note in this context that the initial injuries to the trees were mainly small ("trials") and that significant removal of the bark ("damage") occurred only later. Were the animals sampling for nutrient levels with these early bark removals ? At the time of these early "trials" there would have been much lower levels of nutrients in the vascular tissues than when the large removals of bark occurred.

The young plantations in which the serious bark-stripping occurs almost certainly represent suboptimal habitat for grey squirrels. Sites for drey building are few as are reliable escape routes, but more importantly food supplies are probably much more restricted than in mature stands. At the time of food shortage (May to July), the problems are likely to be most severe in these young stands.

There is some evidence that the animals responsible for bark-stripping are young individuals (Taylor, 1969; Mackinnon, 1976). Thompson (1978) has described the social organisation of the grey squirrel in North America. He has shown that not all of the young animals born into the population are able to remain in the vicinity of their birth. Increased aggressiveness of the adults forces some of the young animals to disperse into suboptimal habitats.

It seems possible that young animals are forced into young plantations (which in any case are of low quality habitat) at a time of severe food shortage and that in the absence of adequate supplies of alternative foods they remove bark to feed on the underlying tissue. An intensive study with a population of known, marked animals would clarify this problem.

No data exist to indicate the point at which grey squirrel damage causes significant decrease in the height or girth increment of trees in addition to timber defects. However, wounds bigger than the "trials" described earlier cause loss of timber quality and must therefore be regarded as potential damage. It was not possible to give a totally accurate picture of past and present years' damage; firstly because some of the badly affected trees had been removed during the thinning operations or because small size wounds had healed over, and secondly because of time and man power limitations. There are however some broad conclusions which can be drawn from the data produced.

It is known that attempts to reduce the grey squirrel population on a nationwide scale, such as bounty schemes, have failed in the past. The long-term results were negligible while both money and time were wasted. Areas as small as the study area have in the past been cleared of all squirrels after intensive use of conventional methods, but the squirrels were replaced again during the succeeding year. It seemed that no long-term control had been achieved. Mosby (1969) during his 6 year study in North Americal found that at least 38 percent of a grey squirrel population could be removed each year (in addition to natural losses) without any obvious reduction of their numbers from year to year. This could be as a result of increased breeding success due to increased availability of food and space and a result of immigration by surplus squirrels from neighbouring areas where less hunting pressure was exercised. Thus, game-keepers' experience has shown that drey-poking and shooting, trapping, snaring or poisoning are only short-term solutions to the bark-stripping problem; These methods should be used only to prevent severe local damage.

Control measures at Dalmeny should therefore be restricted to two periods of the year: the months of breeding (January - February), and a period of 6 - 8 weeks after the flushing of the beech. This second period is only important in the more susceptible woodland (e.g. the hardwood pole stage stands).

It has been reported (Taylor, 1969; Davidson and Adams, 1973; Tittensor, 1975) that damage does not occur every year but seems likely when the population levels are high. It has also been said that success of spring breeding is correlated with good mast years (Shorten, 1954; Smith and Barkalow, 1967). Therefore after a good crop of nuts and acorns followed by a mild winter the forest manager should be prepared to apply more intensive control measures. The aim of these measures is to lower the local squirrel population during the short period of serious bark-stripping to a level at which the extent of damage becomes acceptable. It is expected that the population will recover but the critical period for that year will be over.

Methods such as application or repellents of fencing or improvement of food supply during the bark-stripping period, proposed to reduce the damage caused by other bark-strippers such as rabbits or deer are not applicable to our case since squirrels are mainly arboreal animals. Control measures are economically justified only when the damage is likely to exceed control expenditure, and when applied, the results should be evaluated on the extent by which damage is reduced and not by the number of animals shot. The Forestry Commission's latest report (Melville, 1980) stated that 'no data exist on the point at which squirrel damage causes significant decrease in the girth or height increment in addition to timber defects'. Therefore it is necessary to focus the research on the economic site of the problem or at least work on this particular aspect at the same time as research on methods to control the population (biological approach) is carried out. It is important to know whether any losses (direct or not) due to bark-stripping are severe in long term assessments or whether the damaged trees are the proportion of the trees in the stand which would be removed during the silvicultural operations or whether they (at most) slightly delay felling. The answer to this question is the first step towards a justified decision about the necessity of controlling the number of squirrels. Meanwhile the presence of these animals should be regarded as a site factor as precipitation or soil type are. This means that the potential extent of bark-stripping must be taken into account when new plantations are going to be established and the tree species have to be chosen. The likely sacrifice in production must be balanced by the today's cost of controlling the squirrel population.

It would not be meaningfull to suggest that the vulnerable species such as beech or sycamore should be excluded in future plantations since the animal will probably turn to the next favourable ones. But, it could be suggested that where two species are equally suited to the site, the less preferred one or that with a shorter period of vulnerability should be chosen. If however beech or sycamore have to be used, then phenotypes of them with thick or rough bark at an earlier age should be selected for.

It could also be said that new plantations should not be established at the vicinity of mature oak or beech stands already containing resident squirrels since more animals will have access to them.

Our attention should also be focused to another important point. It has been recorded (Davidson, A.M., 1975) that plantations suffer more than naturally regenerated stands. This record provides additional support to the view that the primary cause for bark-stripping is the search for food since the trees (because of the silvicultural operations are more vigorously growing. It is also well known to the foresters that the less promising trees should be removed during thinnings. The removal of trees already damaged by squirrels will probably result in an increase in the total number of trees damaged since during the next year the animal will attack other trees. It has been shown (page 65) that almost 90 percent of the 1980 injuries started from callus tissue. These trees (even severely damaged) should be treated as the healthy ones and removed according to the silvicultural criteria applied in a stand without damage. This is because the damaged trees until they are dead seem to attract the animal providing a certain amount of forage during the food shortage period and may help to keep the serious damage off other individuals in the vicinity. Forestry Commission workers (F.C. 1962) held the same view (i.e. that the damaged trees should not be removed) but it would be worthwhile to carry out a long-term experiment. When the stand is at the thicket - sapling stage, some trees evenly distributed should be chosen and injured by the forester in order to investigate the possibility that as the trees are grown, the injured ones will receive most of the attacks while the rest will remain unhurt. It could also be examined if the total damage will be less since the secondary effects will be minimised because of the stand structure maintenance.

Another point should also be considered. It has been found (page 63) that beech received less new "damages" on its stem than sycamore did. It has also been found (page 74) that sycamore displayed more cumulative severe damage than beech. Thus, if the manager's objective is beech to be the final timber stock in his stand some sycamore trees in small groups of 3 - 5 individuals should be evenly distributed during the planting. Even if some beech trees are going to be affected it is expected that damage will occur at the butt and if these trees survive and be included in the final crop, the damaged part (stump) will not greatly influence the timber value of the bole.

Finally it should be said that no correlation was found between severe cumulative damage and the size of the plot.

We cannot say that we have explained or solved all the aspects of the problem but we tried to postulate a number of interpretations.

First we are of the opinion that bark-stripping is primarily caused by the animal to obtain some kind of food but a long term study on sap analyses is needed to confirm it.

Secondly, the extent of the total damage is expected to be less if the badly damaged trees are not removed at the early thinnings.

Thirdly, a study of the economic aspect of the problem should be initiated to try to find out whether the damage caused by the animal is financially significant.

Lastly, a suggestion was made to attract the animal to certain specified areas of the stand in order to minimise the extent of damage.

SUMMARY

1. Bark-stripping by the grey squirrel (*Sciurus carolinensis* Gmelin) was studied at Dalmenty Estate, Central Scotland in 1979 and 1980. The purpose of the study was to examine in greater depth than had been done previously, the nature, incidence and severity of grey squirrel bark-stripping, primarily to provide recommendations to foresters for proper control methods. 160 stands of various sizes between seedling and pole stage were examined.

2. In 1979 "damage" by bark-stripping occurred between the fourth week of June and the second week of August. In 1980, the "damages" started in late May, reached a peak during late June to early July, and had ceased by mid August.

3. When total numbers of trees are considered, beech and sycamore received the greatest number of new injuries during the study period. Numbers of Norway maple and elm inspected were low but these two also received a high incidence of new wounds. Ash and horse chestnut were not significantly affected. New injuries were not recorded on oak, birch or conifers. Assessment of "damage" by a single inspection during mid June to mid July in 1980 gave similar results to assessment by numerous regular inspections.

4. The percentage of trees injured and "damaged" increased with increasing dbh of the trees.

5. A highly significant relationship was found between injuries and "damage" and the social position of the tree : dominants and codominants were much more affected than sub-dominants and suppressed trees.

6. Most of the injuries and "damage" occurred at the butt rather than stem of both sycamore and beech. Sycamore received a higher percentage of stem injuries and "damage" than did beech.

7. In both beech and sycamore a very high percentage of new injuries started on callus tissue (Beech, 86.6%; Sycamore, 89.6%).

8. The dimensions of the wounds are described.

9. The timing of injuries was related to the timing of flushing of the leaves of the trees. Beech trees flushed earlier than sycamores and were attacked earlier.

10. The percentage of trees "damaged" in the examined plots showed a great range from 0 to 100 and was not related to the size of the plot or to the dbh class of the trees. In nearly all plots a higher percentage of the sycamore were severely damaged than of the beech.

11. The causes of bark-stripping are discussed. Most of the evidence points to bark-stripping as important feeding behaviour during a period of food shortage.

12. The options available for the management of the grey squirrel problem are discussed.

REFERENCES

ABBOTT, R.J., BEVERCOMBE, G.P., and RAYNER, A.D.M.(1977). Sooty bark disease of sycamore and the grey squirrel. Trans. Br. mycol. Soc. 69(3): 507-8.

AHLEN, I. (1965). Studies on the red deer in Scandinavia. Viltrevy. Vol. 3.

ANDERSON, M. (1956). Management plan for the period 1956-57 to 1966-67 for the woodlands on the Dalmeny Estate in the County of West Lothian. (Professor Taylor's file).

BRENNEMAN, W.S. (1954). Tree damage by squirrels: silviculturally significant. J. For. 52(8): 604.

BURGESS, J.M. (1957). Damage to bark of sycamore by grey squirrels. J. Oxf. Univ. For. Soc. 4(5): 15-16.

CHAPMAN, H.H. (1931). Forest management. Albany, New York. J.B.Lyon Company, publishers.

DAVIDSON, A.M. (1975). The grey squirrel - an evaluation of gastric analysis, the study of diet and of bark damage. Q. J. For. 69: 35-46.

DAVIDSON, A.M. (1975). British squirrels - Between ourselves. Q.J.For. 69: 225-232.

DAVIDSON, A.M. (1976). The red squirrels. Q. J. For. 70: 109-111.

DAVIDSON, A.M., and ADAMS, W. (1973a). The grey squirrel and tree damage. Q. J. For. 67: 237-47.

DAVIDSON, A.M., and ADAMS, W. (1973b). The grey squirrel and tree damage. Q. J. For. 67: 289-307.

ESAU, K. (1965). Plant Anatomy. (Second edition).

ESAU, K. (1977). Anatomy of seed plants.

FORESTRY COMMISSION (1953). Hints on controlling grey squirrels. Leaflet distributed by the Forestry Commission, London.

FORESTRY COMMISSION (1954). Traps for grey squirrels. Instructional leaflet distributed by the Forestry Commission, London.

FORESTRY COMMISSION (1962). The grey squirrel a woodland pest. Leaflet No. 31 distributed by the Forestry Commission, London.

FREESE, F. (1962). Elementary forest sampling. U.S. Dept. Agr., Agr. Handb. 232, 91 pp.

FRITZ, E. (1951). Bear and squirrel damage to young redwood. J. For. 1951 Sept. 651-2.

HOLMES, G.D., and MATTHEWS, J.D. (1951). Girdling or banding as a means of increasing cone production in pine plantations. Forest Record No. 12.

IRVING, F.D. and BEER, J.R. (1963). A six year record of sugar maple bark-stripping by grey squirrels in a Minnesota oak - maple stand. J. For. 61: 508-11.

KNIGHT, M. (1960). The best time to watch squirrels. The Field Magazine (Oct. 6).

LUTZ, H.J. (1951). Damage to trees by black bears in Alaska. J. For. 49: 522-23.

McINTYRE, E.B. (1975). Bark-stripping by ungulates. Unpub. D. Phil. Thesis. Univ. of Edinburgh.

MACKINNON, K.S. (1976). Home range, feeding ecology and social behaviour of the grey squirrel. Ph.D. Thesis, Univ. of Oxford.

MAMMAL SOCIETY (1978). Provisional Atlas of the mammals of the British Isles.

MAXWELL, H.A. (1967). Red deer and forestry with special reference to the highlands of Scotland. Society of Foresters of Great Britain.

MELVILLE, R.C. (1980). Grey squirrel damage in Central Scotland. A Forestry Commission report, Wildlife Branch.

MIDDLETON, A.D. (1930). The ecology of the American grey squirrel (*Sciurus carolinensis* Gmelin) in the British Isles. Proc. Zool. Soc. Lond. 1930, 809-43.

MIDDLETON, A.D. (1931). The grey squirrel. The introduction and spread of the American grey squirrel in the British Isles, its habits, food and relations with the native fauna of the country. London: Sidgwick and Jackson.

MITCHELL, B., STAINES, B.W. and WELCH, D. (1977). Ecology of red deer. Published by I.T.E.

MOSBY, H.S. (1969). The influence of hunting on the population dynamics of a woodlot grey squirrel population. J. Wildl. Mgmt. 33: 59-73.

MULLER, H.J. (1965). Investigation regarding the evaluation of the economically acceptable density of game peeling in forests according to the damage caused by the game and to the site. Archiv. fur Forstwesen Vol.14, No.5 Forestry Commission Translation No. 330.

NIXON, C.M., WORLEY, D.M. and McCLAIN, M.W. (1968). Food habits of squirrels in south east Ohio. J. Wildl. Mgt. 32(2): 294-305.

OGNEV, S.I. (1967). Mammals of the U.S.S.R.and adjacent countries. Vol.V. Translated from Russian (Israel program for scientific translation, Jerusalem 1963).

PELLEW, R.A. (1968). Bark-stripping. A problem in the integrated management of red deer and forestry. Hons. Thesis, Univ. of Edinburgh.

PULLIAINEN, E. and SALONEN, K. (1963). On ring-barking of pine by the squirrel (*Sciurus vulgaris*) in Finland. Annls. Acad. Scient. Fenn. A. IV: 72: 291-329.

RADWAN, M.A. (1969). Chemical composition of the sapwood of four tree species in relation to feeding by the black bear. For. Science 15: 11-16.

REDMOND, H.R. (1953). Analysis of grey squirrel breeding studies and their relation to hunting season, gunning pressure, and habitat conditions. Trans. N. Am. Wildl. Conf. 18: 378-89.

RIJCKEN, P.H.P. (1965). Bark-stripping damage to Scots pine by red deer. Ned. Bobs. Tijdschr. 37(2): 32-65. Forestry Commission Translation No. 255.

ROWE, J.J. (1973). Grey squirrel control. Forestry Commission leaflet No. 56.

SEYMOUR, W. (1961). Grey squirrels. Q. J. For. V.55: 293-298.

SHORTEN, M. (1951). Some aspects of the biology of the grey squirrel (*Sciurus carolinensis*) in Great Britain. Proc. Zool. Soc. Lond. 121: 427-59.

SHORTEN, M. (1954). Squirrels. Collins, London.

SHORTEN, M. (1957a). Damage caused by squirrels in Forestry Commission areas, 1954-6. Forestry 30: 151-172.

SHORTEN, M. (1957b). Squirrels in England, Wales and Scotland 1955. J. Anim. Ecol. 26: 287-94.

SMITH, N.B., and BARKALOW, F.S. (1967). Precocious breeding in the grey squirrel. J. Mammal. 48: 328-30.

STILLINGER, C.R. (1944). Damage to conifers in Northern Idaho by the Richardson red squirrel. J. For. 42: 143-5.

TAYLOR, J.C. (1968). Use of marking points by grey sqirrels. J. Zool. 155: 246-247.

TAYLOR, J.C. (1969). Social structure and behaviour in a grey squirrel population. Unpub. Ph.D. Thesis, Univ. London.

THOMPSON, D.C. (1978). Regulation of a northern grey squirrel (*Sciurus carolinensis*) population. Ecology v.59: 708-715.

TITTENSOR, A.M. (1975). The red squirrel. Forest Record No. 101, London. H.M.S.O.

TITTENSOR, A.M. (1970). The red squirrel (*Sciurus vulgaris* L.) in relation to its food resource. Unpub. Ph.D. Thesis, Univ. Edinburgh.

TOUMEY, J.W. (1947). Foundations of Silviculture. (Sec. edition).

UECKERMANN, E. (1966). The position of prevention of damage caused by game in West Germany. 6th World Forestry Congress, Madrid.

ZIMMERMANN, M.H., and BROWN, C.L. (1971). Trees, structure and function. Springer-Verlag, New York, Heidelberg, Berlin.

WHITE, J. (1962). Damage by red squirrels to larch in Perthshire. Scot. For. 16: 59-60.

WOOD, D.A. (1978). The squirrel problem - Towards a solution ? Q. J. For. 72: 139-143.

APPENDIX I

SPECIES LIST :

Common name	Scientific name
Broadleaved	
Alder	*Alnus glutinosa* L.
Ash	*Fraxinus exelsior* L.
Aspen	*Populus tremula* L.
Common beech	*Fagus sylvatica* L.
Common oak	*Quercus robur* L.
Copper beech	*Fagus purpurea* L.
Elder	*Sambucus nigra* L.
English elm	*Ulmus procera* Salisb.
Hazel	*Corylus avellana* L.
Hornbeam	*Caprinus betulus* L.
Horse chestnut	*Aesculus hippocastanum* L.
Lime	*Tilia vulgaris* Hayne
Norway maple	*Acer platanoides*
Rowan	*Sorbus aucuparia* L.
Silver birch	*Betula pendula* Roth.
Sweet chestnut	*Castanea sativa* M.U.
Sycamore	*Acer pseudoptalanus* L.
Turkey oak	*Quercus cerris* L.
Weeping willow	*Salix tristis* L.
Whitebeam	*Sorbus* spp.
Wild cherry	*Prunus avium* L.
Wych elm	*Ulmus glabra* Huds.
Yew	*Taxus baccata* L.
Conifers	
Corsican pine	*Pinus nigra* var.
Douglas fir	*Pseudotsuga menziesii* Franco
European larch	*Larix decidua* Miller
Grand fir	*Abies grandis* Lindley
Norway spruce	*Picea abies* Karsten
Scots pine	*Pinus sylvestris* L.
Silver fir	*Abies alba* Miller
Sitka spruce	*Picea sitchensis* Carriere
Bushes	
Blackthorn	*Prunus spinosa* L.
Box	*Buxus sempervirens* L.
Bramble	*Rubus* sp.
Dogwood	*Cornus sanguinea* L.
Holly	*Ilex aquifolium* L.
Honey suckle	*Lonicera* spp.
Ivy	*Hedra helix* L.
Laurel	*Prunus* spp.
Privet	*Ligustrum vulgare* L.
Rhododendron	*Rhododendron ponticum* L.
Sea buckthorn	*Hippophae rhamnoides* L.
Snowberry	*Symphoricarpos albus* Blake

APPENDIX II Description of 160 stands which were examined during 1979 in Dalmeny Estate

Plot number	Compt.	Size (ha)	Planting year(s)	Species Composition	Exposure	Silvicultural operations	Fencing	Ground Vegetation	Slope
1	2	3	4	5	6	7	8	9	10
1	100	1.00	66	S B O C	SE	Yes	Damaged	Brambles ' Ferns	Various
2	100	0.80	65	S B A C	SE	Yes	"	" "	"
3	43	0.52	60	S B A C	NE	Yes	"	" "	"
4	42	0.62	76	B O C	NE	No	Yes	Brambles	Slight-medium
5	43	0.28	66	S B O A C	NE	No	Damaged	Ferns	Flat-slight
6	43	0.05	66	S B O A H L	N	No	"	Brambles ' Ferns	" "
7	42	0.61	76	B O C	NW	No	Yes	Dense brambles	Medium-steep
8	42	0.05	66	S B O A H	N	No	Damaged	Ferns	Slight-medium
9	42	o.23	60	S O A	N	Yes	"	Brmables ' Ferns	Slight
10	40	0.06	60	S B A	NE	No	"	Ferns	Medium
11	40	0.08	66	B A	E	No	"	"	Flat
12	40	0.07	66	S B A H	NE	No	"	"	Various
13	40	0.33	66	S B O C	NW	No	"	"	Steep
14	40	0.42	66	S B A C	NW	No	"	Dense brambles	Medium-steep
15	39	1.00	72	S B O A C H	N	No	Yes	" "	Flat-slight
16	39	0.06	72/66	S B A H	N	No	Damaged	Ferns	Slight
17	39	0.19	60	S O	N	No	"	"	Flat
18	39	0.08	66	S B O A H	NE	No	No	Brambles ' Ferns	Flat-slight
19	39	0.05	60	S O A H	N	No	No	Ferns	Flat
20	39	0.07	60	S B O Bi	N	No	Damaged	Brambles ' Ferns	Medium-steep
21	39	0.05	66	S B O A	N	No	"	Scrubs ' Ferns	Steep
22	39	o.05	66	S B O H L	N	No	"	Ferns	"
23	39	0.11	66	B	NE	No	"	Brambles ' Ferns	Very Steep
24	41	0.05	60	S B A C H	N	No	"	Ferns	Slight
25	41	0.05	60	B O A H	NW	No	No	Brambles ' Ferns	"
26	41	0.06	60	S B A H L	W	No	Damaged	Brambles ' Scrubs	"
27	37	0.39	67	S O C	E	No	"	Dense brambles	Flat-slight
28	37	0.07	61	S B A C	NE	No	No	" "	" "
29	36	0.04	61	S B A	SE	No	No	Scrubs	Slight
30	36	0.06	61	S B A Nm	E	No	No	No	Medium
31	36	0.03	61	B	E	No	No	No	Slight
32	34	0.04	61	S B H L	SE	No	No	Scrubs	Medium-steep
33	34	0.26	73/67	S B O C	E	Yes	Damaged	Dense brambles	Flat-slight

APPENDIX II (Continued)

Plot Number	Compt.	Size (ha)	Planting Year(s)	Species Composition	Exposure	Silvicultural operations	Fencing	Ground Vegetation	Slope
1	2	3	4	5	6	7	8	9	10
34	34	1.47	74/67/61	S B C	NW	Yes	Yes	Dense brambles	Flat-slight
35	35	0.07	67	S B O C	W	No	Damaged	Scrubs	Slight
36	35	0.08	67	S B C E	W	No	"	Grasses	"
37	35	0.07	67	S B C E	W	No	"	Ferns	"
38	35	0.03	61	S B E	E	No	"	Brambles	"
39	36	0.09	61	S B E	E	No	"	Scrubs	Flat
40	36	0.06	61	S A L	E	No	No	Ferns	Slight
41	36	0.05	61	S B A	SE	No	No	Brambles ' Ferns	"
42	36	0.44	67	S B C	SE	No	Damaged	Brambles ' Scrubs	"
43	38	0.09	66	S B O H L	NE	No	"	Ferns	Flat
44	38	0.06	75	S B O	NE	No	No	Dense bramble	"
45	38	0.08	66	S B O C H L	NE	Yes	No	Ferns	"
46	38	0.26	75	B C	NE	No	Yes	Dense brambles	"
47	38	0.05	66	S B O C	NE	No	No	Ferns	"
48	38	0.33	60	S B O A C	NE	Yes	No	No	"
49	108	0.20	66	B O A	E	No	Yes	Brambles	Slight
50	109	0.48	72	S B O C	NE	No	Yes	Dense brambles	Medium
51	33	0.24	61	S B O	S	No	No	" "	Flat
52	102	2.75	65	S B C	N	No	Yes	Brambles ' Scrubs	Slight-medium
53	33	3.00	67	S B O C	NW	Yes	Yes	Brambles ' Ferns	Flat
54	32	0.20	70	C	S	No	No	Grasses	Slight
55	32	0.35	67	S B O	N	No	Damaged	Brambles ' Ferns	"
56	32	0.05	67	S B O A	NW	No	No	No	"
57	27	0.07	59	S B A C	S	No	No	No	"
58	27	0.18	65	S B C	NE	Yes	No	Brambles	Slight-medium
59	27	0.11	65	B A C	NE	Yes	Damaged	Brambles ' Ferns	Slight
60	29	0.05	61	S B O H E	W	No	"	" "	Flat
61	29	0.32	67	S B O C H	NW	No	"	Dense brambles	Slight
62	29	0.05	67	S B O H E	NW	No	"	Ferns	Flat
63	30	0.32	67	S B O	N	Yes	"	Brambles ' Ferns	Slight
64	30	0.05	61	S B O H	NW	No	No	Ferns	Flat
64	30	0.05	67	S B A H	SE	No	Damaged	Brambles ' Ferns	Slight
66	25	0.07	63	S B O A H E	W	No	"	Brambles	Steep
67	25	0.07	65	S B A H E	W	No	"	No	Various
68	25	0.32	59	S B H	W	No	"	Brambles	Medium
69	26	0.22	59	B O A	E	No	"	"	Slight

APPENDIX II (Continued)

Plot Number	Compt.	Size (ha)	Planting Year(s)	Species Composition	Exposure	Silvicultural operations	Fencing	Ground Vegetation	Slope
1	2	3	4	5	6	7	8	9	10
70	106	1.20	72	B C	S	No	Yes	Dense brambles	Slight
71	23	0.05	59	S B A	W	Yes	No	Brambles	Medium
72	23	0.03	65	S B O A	S.	No	No	"	Steep
73	23	0.07	65	B O A C	NW	No	Damaged	Brambles ' ferns	Medium
74	23	0.07	59	S O C	NW	No	"	" "	"
75	23	2.20	73/65	S B O C	S	No	Yes	Dense brambles	Various
76	24	0.41	65	S B O A C	E	No	Damaged	Brambles ' ferns	Medium
77	22	0.26	69	S B O A C	NE	No	"	" "	Flat-slight
78	22	6.37	72/69/65	S B O C	NE	No	Yes	" "	Various
79	22	0.09	65	B O A C	W	No	No	Ferns	Medium
80	24	0.08	59	S B O C E/B	S	No	No	No	Slight
81	24	0.05	65	S B E	E	No	No	Brambles ' ferns	"
82	24	0.19	65	S B O A E	SE	No	No	No	Flat
83	110	2.00	72	S C	E	No	Yes	Dense brambles	Various
84	110	0.18	72	S B O	SE	No	Yes	" "	Steep
85	7	0.06	62	S B A Ac	N	No	Damaged	No	Slight
86	4	1.15	63	S B O A C	W	Yes	"	Brambles	Medium-steep
87	4	0.06	62	S B O A	N	No	"	No	Medium
88	5	1.02	69	S B O	N	No	"	Ferns	Various
89	6	0.04	62	S B O LBi	NE	No	"	"	Medium
90	7	0.05	62	S B A	N	No	"	No	Slight
91	7	0.04	62	B A a	N	No	No	Brambles	"
92	7	0.07	62	S B O	NE	No	Damaged	No	Medium-steep
93	23	0.05	65	S B O C E	W	No	No	No	Flat
94	19	0.10	71	S B O A	W	Yes	Damaged	No	"
95	19	0.06	71	S B O A	N	Yes	"	No	Slight
96	19	0.06	71	S B O A	NW	Yes	"	No	Flat
97	20	3.30	71/63	S B O C	N	No	"	Brambles ' Ferns	Various
98	19	0.34	63	S O A C	N	Yes	"	Brambles	Flat
99	113	4.80	52	S A C	SE	Yes	Yes	No	Various
100	112	0.30	72	C	N	No	Yes	Dense brambles	Slight
101	9	0.07	57	S B A Bi	NW	no	No	No	Flat
102	11	0.07	64	S B O A	NW	No	No	Ferns	Slight
103	11	0.08	64	S B A C E	W	No	No	No	"
104	11	0.39	64	S N O A E	E	Yes	Damaged	No	"
105	13	0.07	58	S B C	SE	No	No	No	"
106	13	0.07	64	A B A H E	SE	No	No	No	Flat

APPENDIX II (Continued)

Plot Number	Compt.	Size (ha)	Planting Year(s)	Species Composition	Exposure	Silvicultural operations	Fencing	Ground Vegetation	Slope
1	2	3	4	5	6	7	8	9	10
107	13	0.03	58	S B H E	SE	No	Damaged	Brambles	Slight
108	17	0.05	63	S B O C	SE	No	"	"	Medium
109	17	0.06	63	S B O A	S	No	"	Dense brambles	"
110	17	0.40	74	S B	S	No	Yes	" "	"
111	13	0.34	58	S B O A	SE	No	Damaged	Brambles	Slight-medium
112	12	0.33	64	S B O	SE	Yes	"	"	" "
113	13	0.08	64	B C	SE	Yes	"	"	Medium
114	16	0.06	63	O C Bi	SE	No	"	Dense brambles	Slight
115	17	0.05	53	S B O A	SE	No	"	" "	Medium
116	16	0.22	53	S O A C	S	No	"	" "	"
117	16	0.68	74/63	S B O C	S	No	Yes	" "	"
118	18	0.05	63	S B O	N	No	Damaged	" "	Slight
119	18	0.06	63	S B O C	SW	No	"	Brambles ' Ferns	"
120	18	0.06	63	S O C	S	No	"	Dense brambles	"
121	18	0.07	63	S O C	S	No	"	Ferns	"
122	16	0.05	63	S B O C	W	No	"	Dense brambles	"
123	16	0.06	63	A B O C	W	No	"	" "	"
124	16	0.07	63	S B O C	W	No	"	" "	Flat
125	16	0.08	63	B O C	W	No	"	" "	Slight
126	12	0.03	71	S B O	NW	No	"	No	"
127	12	0.45	58	S B O	N	Yes	"	Ferns	Medium
128	12	0.56	71/58	S B O C Bi	N	No	Yes	Brambles ' ferns	"
129	12	0.06	64	S B Bi	N	No	Damaged	No	Flat
130	10	0.36	67	S B O A C	NW	Yes	"	Brambles ' ferns	Slight
131	10	0.60	71	S B O C	N	No	Yes	" "	"
132	10	0.30	58	S B O Bi	N	Yes	Damaged	Ferns	"
133	11	0.09	58	S B O H Bi	N	Yes	No	"	"
134	11	0.65	71	S B C	N	No	Yes	"	Flat-medium
135	11	0.73	64	S B A	N	Yes	Damaged	"	Medium
136	9	0.80	70	B C	N	No	"	"	Flat-slight
137	9	4.17	70/64/57	S B A C E	NW	Yes	Yes	Brambles ' ferns	Various
138	8	2.50	70/64/57	S B O C	NW	Yes	No	" "	Medium
139	114	0.35	76	B	W	No	Damaged	" "	"
140	114	0.10	68	S B O C	NW	No	"	" "	Flat
141	114	0.19	76	B O	NW	No	Yes	Brambles	"

APPENDIX II (Continued)

Plot Number	Compt.	Size (ha)	Planting Year(s)	Species Composition	Exposure	Silvicultural operations	Fencing	Ground Vegetation	Slope
1	2	3	4	5	6	7	8	9	10
142	114	0.08	68	S B C	NW	No	No	Brambles	Slight
143	1	0.07	62	S B A	NW	No	Damaged	Brambles ' ferns	Medium
144	1	0.19	75	B O	NW	No	Yes	Dense brambles	"
145	1	0.06	62	S B O A	W	No	No	No	Flat
146	1	0.25	75	B	W	No	No	Grasses	"
147	1	0.06	75	S B	NW	No	Yes	Dense brambles	Slight
148	1	0.05	62	S B O	NW	No	Damaged	Ferns	Flat-medium
149	1	0.08	75	B	NW	No	Yes	Dense brambles	Steep
150	1	0.07	62	S B A L	NW	No	Damaged	Brambles ' ferns	Medium-steep
151	15	0.08	63	S O A C	NW	No	"	Ferns	Medium
152	15	0.09	63	S A	NW	No	No	Brambles	Flat
153	15	0.06	63	S B O A	NW	No	Damaged	Brambles ' ferns	Slight-medium
154	15	0.06	63	S B O A	NW	No	"	" "	Medium
155	15	0.07	63	S B O A	NW	No	"	Ferns	Slight-medium
156	15	0.07	63	S B A	NW	No	"	"	Steep
157	14	0.06	63	S B O A	NW	No	"	Brambles ' ferns	"
158	14	0.07	63	S O A	NW	No	"	" "	Medium
159	14	0.05	63	S B	NW	No	"	No	Steep
160	15	0.31	75	S B	NW	No	Yes	Dense brambles	Slight

APPENDIX III The form used to record details of injuries in the field.

In order to record the various types of injuries in the formats a code of symbols and letters was used.

Each tree examined was measured with a rounded down diameter tape and its class of diameter was entered in the d.b.h. (diameter at the breast height) column of the format. The tree was inspected as carefully as possible for old and/or new injuries of any size at the butt, stem and branches.

If no wounds were seen, the symbol ✓ was entered under the heading "Absent". (see form on page 108)

If old wounds were found the small letters l, m or h were used under the corresponding column butt and/or stem and/or branches. A capital letter L, M or S was then entered under the heading "Present" to describe the seriousness of the damage for that individual tree.

If recent injuries were encountered, additional remarks were recorded about their number on the same tree, dimensions, location and aspect on the tree, starting from callus or intact bark, appearance of the wound surface and determination of the approximate date of attack

Two examples taken from a specimen form (page 108) will better illustrate the situation.

The record for sycamore No. 12 is d.b.h. = 14 cm

Damage : moderate at the butt and severe at the stem

General description of the damage : S (severe)

For beech No. 29 I have noted : d.b.h. = 5 cm.

Damage : moderate at the butt and light at the stem

General description of the damage : M (moderate)

For the ashes we can see that out of thirty trees examined only two bore damage, both at the butt.

The form used to record details of injuries in the field

The Plot

No. 14 Compartment 40   Size 0.42 (ha) Shape   (Not to scale

The Stand

Composition S, B, A, .   Age: 17 (years)

Locality factors

Aspect N   Exposure NW   Slope medium-steep   Ground veg. dense brambles

Other factors

Disturbance : Adjacent to a ride

Fence : old, damaged

Silvicultural operations : ø

Pheasants' feeding places : ø

NEW INJURIES

No.	Species	d.b.h.	Date approx.	Location: Butt	Location: Stem	Location: Branches	Dimensions (cm)	Aspect	Remarks
16	S	20	11/6		√		3 x 2	N	On bark
1	B	8	11/6	√			1 x 1	N	On Callus
4	B	16	3/6	√			3 x 2.5	W	On Callus
25	B	5	8/6	√			1.5 x 1	S	On bark
*	B	9	10/6	√			20 x 8	NE	On bark
							4 x 4	N	On bark

Date: 11/6/1980

				Old Injuries							Old Injuries							Old Injuries				
Number	Species	d.b.h.	Absent	Present	Butt	Stem	Branches	Species	d.b.h.	Absent	Present	Butt	Stem	Branches	Species	d.b.h.	Absent	Present	Butt	Stem	Branches	Species
1	S	6	–	S	–	s	–	B	8	✓					A	7	✓					Conifers - no injuries
2	"	7	–	M	m	m	–	"	8	✓					"	8	✓					
3	"	5	–	S	l	s	–	"	13	–	M	m	m	–	"	6	✓					
4	"	6	–	S	l	s	–	"	16	–	S	s	–	–		11	✓					
5	"	5	–	M	–	m	–	"	4	✓					"	5	✓					
6	"	10	–	S	s	s	–	"	7	✓					"	4	✓					
7	"	9	–	S	l	s	–	"	5	✓					"	4	✓					
8	"	5	–	L	l	l	–	"	5	✓					"	6	✓					
9	"	14	–	L	–	l	–	"	5	✓					"	9	✓					
10	"	19	–	S	–	s	–	"	5	✓					"	6	✓					
11	"	14	–	S	–	s	–	"	5	✓					"	6	✓					
12	"	14	–	S	m	s	–	"	13	–	S	s	m	–	"	10	✓					
13	"	13	–	M	m	m	–	"	8	✓					"	6	✓					
14	"	11	–	M	–	m	–	"	4	✓					"	4	✓					
15	"	10	–	M	–	m	–	"	3	✓					"	4	✓					
16	"	20	–	S	m	s	–	"	3	✓					"	7		L	l	–	–	
17	"	5	–	L	–	l	–	"	5	✓					"	6	✓					
18	"	5	✓					"	6	✓					"	5	✓					
19	"	7	–	M	–	m	–	"	4	✓					"	7	✓					
20	"	6	–	S	–	s	–	"	9	✓					"	8	✓					
21	"	6	–	S	–	s	–	"	9	✓					"	6	✓					
22	"	4	–	S	–	s	–	"	14	✓					"	4		M	m	–	–	
23	"	6	–	S	–	s	–	"	7	✓					"	4	✓					
24	"	3	✓					"	7	✓					"	5	✓					
25	"	5	–	M	–	m	–	"	5	✓					"	4	✓					
26	"	9	–	S	–	s	–	"	6	✓					"	6	✓					
27	"	10	–	S	–	s	–	"	4	✓					"	5	✓					
28	"	7	–	S	–	s	–	"	3	✓					"	10	✓					
29	"	5	–	L	–	l	–	"	5	–	M	m	l	–	"	8	✓					
30	"	7	–	S	–	s	–	"	4	✓					"	7	✓					

APPENDIX IV: A rough field guide to estimate the approximate date when the "damage" was done on beech or sycamore

During 1980 when the plots (5, 9, 50, 102, 104 and 115) were regularly inspected, special attention was paid to observing the successive changes in the appearance and texture of the new wounds. In addition to these regularly visited sites, further records were kept for injured beech and sycamore trees in other stands of the estate. In the estimation of the data when "damage" occurred, three factors were taken into account.

a) The general appearance and texture of the injured area,

b) The appearance of the exposed but intact cambium tissue, and

c) The appearance and flexibility of the discarded flakes.

Cuts were also made in some of the wounds in order to study (b) and (c) more effectively (See Plates 6 and 10).

More than 50 "damages" were inspected from each species and the results have been summarised (Table). A number of photographs of the same "damage" at different times are presented to illustrate the visual changes in the appearance of the wound as it gets older.

Age of injury	BEECH Injured area	Exposed cambium	Discarded flakes	SYCAMORE Injured area	Exposed cambium	Discarded flakes
2-3 hours	Very moist shaggy texture	Very moist	Very moist tooth marks very clear	Very moist shaggy texture	Very moist	Very moist and flexible
1 day	Moist colour light-beige	Moist colour cream	Flexible colour cream tooth marks tan	Very moist colour white to cream	Moist colour white to creamy	Colour white to cream Tooth 'mark well distinguished
2 days	Moist colour light tan	colour beige to light tan	Their outline turns to tan	Moist colour cream	Moist colour cream	Cry. Tooth marks darker
1 week	Mould appears	No mould	Shrinked colour tan	Colour beige with dark spots	Colour cream-beige	Colour beige
2 weeks	Greyish thick mould	Thin mould has appeared	Colour dark tan	Aubergine colour	Colour beige to aubergine	Start to shrink
3 weeks	Mould starts to disappear colour dark-brown	No mould colour tan	Colour dark-brown to black not flexible	Mould appears	If the surface is is scratched underlying tissue re-vealed as greenish	Colour varied from beige to to aubergine not flexible
1 month	Colour dark brown to black with greyish spots of mould	If the surface is scratched the under-lying tissue is revealed to be greenish	Colour black	No mould	Underlying tissue is green	Colour black

TABLE : Appearance of "damages" at different times.

N.B. Wounds older than one year can be aged by cutting a wedge-shaped block from the callus growth and counting the annual rings since the year of the damage (Burgess, 1954).

PLATE 3: Plot 104 (pole-stage stand). Beech No. 803 (d.b.h.11 cm)
Two "damage" injuries on callus tissue (8.7.80)
One day old (previous inspection 7.7.80)

PLATE 4: "Damage" on beech No. 803, 6 days old.

PLATE 5: "Damage" on beech No. 803, 10 days old

PLATE 6: "Damage" on beech No. 803, 25 days old

PLATE 7: Plot 5 (pole-stage stand). Sycamore No. 229 (d.b.h. 10cm)
One "damage" injury on callus tissue.
A few hours old (4.7.80).

PLATE 8: "Damage" on sycamore No. 229, two weeks old

PLATE 9: "Damage" on sycamore No. 229, three weeks old

PLATE 10: "Damage" on sycamore No. 229, four weeks old.

PLATE 11: Plot 5 (pole-stage stand). Sycamore No. 323 (d.b.h. 7 cm).
One "damage" injury on bark.
A few hourse old (15.7.80).

PLATE 12: "Damage" on sycamore No. 323, one week old.

APPENDIX V Levels of damage in all plots which contained either beech or sycamore or both.

*Percentage is not given because of the small number of trees examined.

/Beech or sycamore absent.

Plot number (1)	Tree Species (2)	Mean dbh (cm) (3)	Size (ha) (4)	Percentage damaged (5)	Percentage light (6)	Percentage moderate (7)	Percentage severe (8)
1	S	8	1	86.7	6.7	43.3	36.7
	B	7		63.0	26.0	18.5	18.5
2	S	8	0.8	66.7	26.7	13.3	26.7
	B	6		3.7	3.7	0	0
3	S	6	0.52	80.0	6.7	26.7	46.6
	B	6		63.3	10.0	13.3	40.0
5	S	5	0.38	68.0	21.0	13.5	33.4
	B	6		71.0	21.0	23.7	26.3
6	S	7	0.05	*			
	B	9		62.1	31.0	24.1	7.0
9	S	7	0.23	76.5	27.5	13.7	35.3
	/						
11	/		0.08				
	B	5		30.0	13.3	16.7	0
13	S	6	0.33	90.0	3.3	43.3	43.4
	B	4		6.7	0	6.7	0
14	S	8	0.42	93.3	13.3	23.3	56.7
	B	7		13.3	0	6.6	6.7
15	S	6	1	76.7	16.7	36.7	23.3
	B	8		20.0	5.7	14.3	0
17	S	6	0.19	93.3	0	13.3	80.0
	/						
18	S	6	0.08	93.3	3.3	40.0	50.0
	B	4		*			
19	S	7	0.05	93.3	6.7	13.3	73.3
	/						
20	S	6	0.07	93.3	3.3	23.3	66.7
	B	5		96.7	0	30.0	66.7
21	S	5	0.05	76.7	16.7	30.0	30.0
	B	5		*			
22	S	6	0.05	100	0	28.0	72.0
	B	5		46.4	25.0	21.4	0
23	/		0.11				
	B	6		3.8	3.8	0	0
24	S	10	0.05	*			
	B	5		67.9	10.7	25.1	32.1
25	/		0.05				
	B	5		86.7	3.3	40.1	43.3
26	S	6	0.06	85.0	20.0	25.0	40.0
	B	6		66.7	18.5	37.0	11.2
27	S	8	0.39	100.0	6.7	13.3	80.0
	/						
28	S	9	0.07	96.0	4.0	20.0	72.0
	B	8		58.8	0	17.8	41.0

APPENDIX V (Continued)

Plot number (1)	Tree Species (2)	Mean dbh (cm) (3)	Size (ha) (4)	Percentage damaged (5)	Percentage light (6)	Percentage moderate (7)	Percentage severe (8)
29	S	5	0.04	70.0	25.0	25.0	20.0
	B	5		*			
30	S	8	0.06	94.1	5.9	8.9	79.3
	B	6		42.9	11.9	19.0	12.0
31	/		0.03				
	B	5		53.6	7.2	35.7	10.7
32	S	7	0.04	*			
	B	8		80.0	16.7	30.0	33.3
33	S	8	0.26	22.8	11.4	11.4	0
	B	11		*			
34	S	7	1.47	75.0	10.7	42.9	21.4
	B	6		40.0	10.0	23.3	6.7
35	S	6	0.07	100.0	0	28.0	72.0
	B	6		*			
36	S	6	0.08	97.7	0	25.0	72.7
	B	6		*			
37	S	6	0.07	90.3	9.7	41.9	38.7
	B	6		83.9	6.5	41.9	35.5
38	S	7	0.03	95.2	4.8	47.6	42.8
	B	6		*			
39	S	8	0.09	92.0	8.0	30.0	54.0
	B	4		44.4	11.1	27.8	5.6
40	S	8	0.06	97.1	8.6	14.3	74.2
	/						
41	S	5	0.05	83.3	26.7	26.6	30.0
	B	5		63.0	18.5	26.0	18.5
42	S	8	0.44	90.0	3.3	33.0	53.0
	B	5		70.0	16.7	20.0	33.3
43	S	7	0.09	*			
	B	6		30.9	9.1	20.0	1.8
45	S	6	0.08	100.0	4.6	40.4	55.0
	B	5		14.8	5.3	5.3	5.2
47	S	6	0.05	100.0	0	0	100.0
	B	6		75.0	0	29.2	45.8
48	S	6	0.33	93.3	0	16.7	76.7
	B	9		76.7	6.7	50.0	20.0
49	/		0.2				
	B	8		50.0	11.5	30.8	7.7
50	S	5	0.48	45.5	31.9	6.8	6.8
	B			0			
51	S	8	0.24	13.3	13.3	0	0
	B	7		3.3	0	3.3	0
52	S	8	2.75	0			
	B	9		26.7	6.7	20.0	0
53	S	7	3.0	40.0	10.0	26.7	3.3
	B	7		3.3	3.3	0	0
55	S	8	0.35	73.3	10.0	23.3	40.0
	B	6		13.4	6.7	6.7	0
56	S	8	0.05	96.9	15.6	28.1	53.2
	B	5		*			
57	S	9	0.07	*			
	B	8		40.0	10.0	25.0	5.0

APPENDIX V (Continued)

Plot number (1)	Tree Species (2)	Mean dbh (cm) (3)	Size (ha) (4)	Percentage damaged (5)	Percentage light (6)	Percentage moderate (7)	Percentage severe (8)
58	S	5	0.18	10.0	3.3	6.7	0
	B	5		0			
59	/		0.11				
	B	6		46.7	6.7	20.0	20.0
60	S	9	0.05	94.1	0	35.3	58.8
	B	5		40.7	29.6	11.1	0
61	S	11	0.52	86.7	10.0	56.7	20.0
	B	7		*			
62	S	7	0.05	65.0	15.0	20.0	30.0
	B	5		42.3	3.9	19.2	19.2
63	S	8	0.32	100.0	3.3	10.0	86.7
	B	5		56.7	20.0	16.7	20.0
64	S	8	0.05	100.0	4.4	0	95.6
	B	6		94.7	0	36.8	57.9
65	S	6	0.05	94.7	15.8	52.6	26.3
	B	4		*			
66	S	6	0.07	96.0	12.0	16.0	68.0
	B	5		*			
68	S	6	0.32	100.0	0	6.7	93.3
	B	6		90.0	3.3	6.7	80.0
69	/		0.22				
	B	5		96.0	0	12.0	84.0
71	S	9	0.05	100.0	0	5.6	94.4
	B	6		62.9	22.9	40.0	0
72	S	7	0.03	100.0	0	5.9	94.1
	B	9		*			
73	/		0.07				
	B	7		71.4	9.5	38.1	23.8
74	S	8	0.07	100.0	0	0	100.0
	/						
77	S	6	0.26	100.0	3.4	13.3	83.3
	B	8		100.0	4.2	16.7	79.1
80	S	9	0.08	100.0	2.6	0	97.4
	B	6		*			
81	S	8	0.05	100.0	0	13.3	86.7
	B	6		60.0	3.3	36.7	20.0
82	S	6	0.19	90.0	0	26.7	63.3
	B	7		44.8	10.3	17.3	17.2
85	S	6	0.06	*			
	B	6		100.0	4.6	36.4	59.0
86	S	7	1.15	100.0	3.3	33.4	63.3
	B	6		43.3	13.3	30.0	0
87	S	8	0.05	100.0	0	0	100.0
	B	9		100.0	0	4.4	95.6
88	S	6	1.02	96.7	0	6.7	90.0
	B	5		93.3	6.7	26.6	60.0
89	S	5	0.04	100.0	0	4.8	95.2
	B	7		*			
90	S	5	0.05	88.9	0	11.1	77.8
	B	6		100.0	0	20.0	80.0

APPENDIX V (Continued)

Plot number (1)	Tree Species (2)	Mean dbh (cm) (3)	Size (ha) (4)	Percentage damaged (5)	Percentage light (6)	Percentage moderate (7)	Percentage severe (8)
92	S	6	0.07	100.0	5.6	16.7	77.7
	B	7		95.8	O	8.3	87.5
93	S	5	0.05	94.7	5.3	7.8	81.6
	B	5		84.0	4.0	28.0	52.0
94	S	6	0.1	73.6	9.4	35.9	28.3
	B	8		*			
95	S	8	0.06	80.0	3.3	33.4	43.3
	B	10		*			
96	S	7	0.06	100.0	5.0	5.0	90.0
	B	6		95.2	4.8	23.7	66.7
97	S	7	3.3	6.7	3.3	3.4	O
	B	6		6.7	3.3	3.4	O
98	S	10	0.34	79.3	3.4	27.6	48.3
	/						
101	S	10	0.07	*			
	B	7		38.7	3.2	12.9	22.6
102	S	8	0.07	63.5	45.3	11.6	6.6
	B	10		*			
103	S	9	0.08	89.3	O	21.4	67.9
	B	6		75.0	O	40.0	35.0
104	S	7	0.39	74.6	17.9	13.3	43.4
	B	7		39.0	13.9	8.4	16.7
105	S	9	0.07	95.2	O	28.6	66.6
	B	7		90.3	12.8	32.3	45.2
106	S	7	0.07	73.9	13.0	30.5	30.4
	B	5		*			
108	S	6	0.05	90.0	3.4	23.3	63.3
	B	6		*			
109	S	6	0.05	97.8	O	33.4	64.4
	B	6		100.0	9.1	18.2	72.7
111	S	7	0.34	100.0	6.7	33.3	60.0
	B	8		93.3	3.3	10.0	80.0
112	S	7	0.33	96.7	O	3.3	93.4
	B	7		85.8	O	42.9	42.9
115	S	5	0.05	81.1	9.8	7.4	63.9
	B	4		80.6	32.3	12.8	35.5
116	S	9	0.22	100.0	O	3.3	96.7
	/						
117	S	8	0.68	100.0	O	O	100.0
	B	8		100.0	3.3	36.7	60.0
118	S	6	0.05	100.0	O	3.3	95.7
	B	8		98.1	5.7	18.8	73.6
119	S	7	0.06	92.0	4.0	8.0	80.0
	B	7		85.2	3.7	22.2	59.3
121	S	5	0.07	94.4	22.1	5.6	66.7
	/						
122	S	4	0.05	91.3	O	O	91.3
	B	7		85.7	2.4	4.7	78.6
124	S	5	0.07	*			
	B	6		100.0	O	O	100.0
125	/		0.08				
	B	6		84.0	O	5.0	79.0

APPENDIX V (Continued)

Plot number (1)	Tree Species (2)	Mean dbh (cm) (3)	Size (ha) (4)	Percentage damaged (5)	Percentage light (6)	Percentage moderate (7)	Percentage severe (8)
127	S	6	0.45	80.0	16.7	16.7	46.6
	B	8		70.0	0	26.7	43.3
128	S	8	0.56	53.0	3.3	33.0	16.7
	B	8		48.0	9.8	19.1	19.1
129	S	7	0.05	95.7	4.3	34.9	56.5
	B	6		*			
130	S	8	0.36	83.3	10.0	30.0	43.3
	B	7		80.0	23.3	43.3	13.4
131	S	5	0.60	40.0	6.6	20.0	13.4
	B	12		*			
132	S	7	0.30	73.3	6.6	16.7	50.0
	B	8		33.3	10.0	10.0	13.3
133	S	9	0.09	*			
	B	7		60.4	7.6	24.8	28.0
135	S	8	0.73	76.7	0	33.4	43.3
	B	8		60.0	16.7	20.0	23.3
136	/		0.80				
	B	6		10.0	3.3	3.3	3.4
137	S	9	4.17	86.7	3.3	40.0	43.4
	B	9		80.0	5.0	35.0	40.0
138	S	7	2.50	63.3	6.7	33.3	23.3
	B	9		*			
140	S	7	1.10	86.7	3.3	33.4	50.0
	B	6		20.0	3.3	10.0	6.7
142	S	8	0.08	36.7	3.3	13.4	20.0
	B	7		26.7	23.4	3.3	0
143	S	6	0.07	*			
	B	5		57.7	7.7	26.9	23.1
145	S	7	0.06	22.3	5.6	16.7	0
	B	8		*			
148	S	9	0.05	*			
	B	10		75.0	14.3	48.4	14.3
150	S	6	0.07	85.7	3.6	35.7	46.4
	B	6		*			
151	S	7	0.08	98.0	16.3	14.3	67.4
	/						
152	S	9	0.09	76.9	11.4	26.9	38.5
	/						
153	S	6	0.06	41.9	12.9	16.1	12.9
	B	6		6.7	6.7	0	0
154	S	6	0.06	3.2	0	3.2	0
	B	6		16.2	8.1	8.1	0
155	S	7	0.07	68.8	0	34.4	34.4
	B	6		19.2	15.4	3.8	0
156	S	7	0.07	94.3	5.7	14.3	74.3
	B	5		*			
157	S	7	0.06	81.0	9.5	23.8	47.7
	B	5		0			
158	S	7	0.07	56.0	4.0	28.0	24.0
	/						
159	S	5	0.05	3.8	0	3.8	0
	B	5		0			