DUTCH ELM DISEASE IN CENTRAL SCOTLAND

Ruth Neiland and J. W. Shepherd

INTRODUCTION

Dutch elm disease is one of the most destructive plant diseases known to Man. It infects most European and American species of elm, and has killed millions of trees throughout the Northern Hemisphere. In Britain alone 20 million elms, almost 90% of the population, have died (Gibbs 1979), the majority over the last two decades. This loss has had a devastating effect on the landscape of many areas, especially in southen England where elms were planted extensively in hedgerows. In Scotland too losses have been considerable, and Greensill (1977) identified Central Region as the most heavily infected part of the country.

Since 1977 many more elms have died, but there has also been considerable research into the disease and we now know a great deal more about control methods. Our aims in this paper are to-

(1) Discuss some of the recent findings as they relate to the ecology of Dutch elm disease in Scotland.
(2) Update information on the control of Dutch elm disease.
(3) Describe the progress of Dutch elm disease in central Scotland.

THE ECOLOGY OF DUTCH ELM DISEASE IN SCOTLAND

Dutch elm disease has only become a problem in Scotland since about 1970. In the 1920s and 30s when the first major known epidemic was sweeping across the south of England, very few cases were reported in Scotland, and most of these were confined to the Borders. The most northerly infection was in an avenue of elms between Inverkeithing and Cowdenbeath in Fife (Burdekin 1979). Also, mortality was the rare amongst infected trees. In the 1970s the disease became more widespread in Scotland, but the rate of infection was lower than in southern England (Greig and Gibbs 1983) although many trees died. In order to understand this pattern of disease development, it is necessary to study the ecology of Dutch elm disease with reference to the environmental factors influencing (a) the elm trees, (b) the pathogen (a fungus called *Ceratocystis ulmi)* and (c) the disease vector (beetles of the genus *Scolytus).*

(a) The Host

Elms are the only plants affected by the disease. There are several species and hybrids of elm in Britain, they vary in size, shape and appearance, but all share the characteristic oval, toothed leaves that grow singly on twigs and are usually asymmetric at the base (Figure 1). Infected

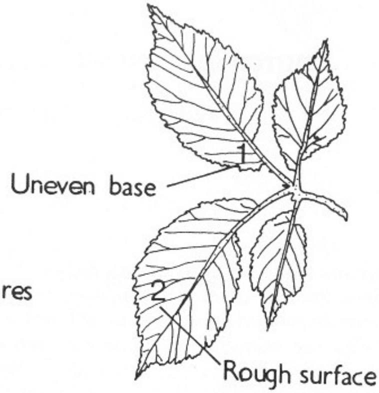

Fig. 1. Characteristic features of elm leaves.

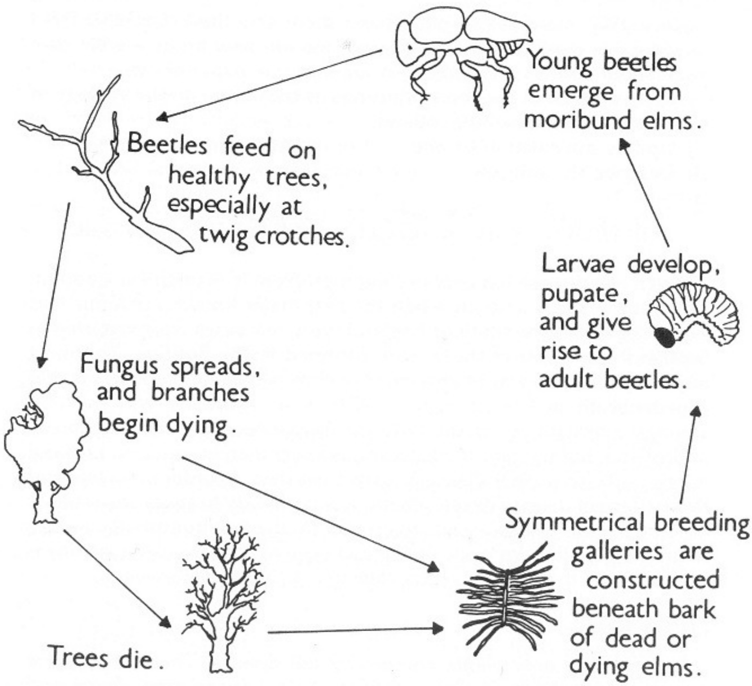

Fig. 2. Life cycle of *Scolytus* beetles.

trees show disease symptoms from mid-summer when the leaves become chlorotic (turn yellow) and the younger shoots tend to wilt. Initially this may only involve a few shoots which die back from the tip, but the symptoms usually spread and sometimes the tree may die within the first year, although some trees take several years to succumb.

Elms are thought to have grown in Britain for about two million years, although their numbers have fluctuated over that time. They disappeared completely during glaciations, but returned again with the milder climate of the interglacials (Moore 1985). The most recent invasion was about 9,000 years ago, after which their numbers dramatically increased, so that in southern England and Ireland the elm became the most common woodland tree. At the end of the Atlantic period however there was a rapid decline which did not affect other trees (Rackham 1980). Between 2900 and 3300 BC, about half the elm disappeared from Europe apparently because of Neolithic farming practices including the use of elm leaves as animal fodder, although disease may also have contributed. Certainly Man has had an important influence on the distribution of elms in more recent years. While woodland clearances have continued, elms were planted throughout Britain often outside their natural range in hedgerows, parklands and towns to fulfill various visual roles, and as a source of strong timber. They became a familiar component of the "typical" British lowland landscape, and were important as a habitat for birds and other wildlife.

The three most common elm species are the English Elm *(Ulmus procera),* the Wych Elm *(Ulmus glabra),* and the Smooth-Leaved or Wheatley Elm *(Ulmus carpinifolia).* All are liable to infections, but the English Elm is most prone to the disease (Brasier 1977), apparently because of its relative attractiveness to the disease vector, the elm bark beetle *(Scolytus* species). Experimental work by Webber and Kirby (1983) for example suggested that elms were selected for feeding by the beetles on the basis of their physical characteristics andchemicalvolatiles. English Elms are preferred because their rough bark is thought to stimulate feeding, as opposed to the smooth barks of the other elm species, and this initial preference is reinforced whenfeeding damage to the trees causes an increased release of host vola tiles (such as oo-cubebene, Byers et al1981) which makes them even more attractive to the beetles. Further aggregation behaviour seems to be mediated by chemical pheromones produced by the beetles themselves when they feed on the host. A number of pheromones can be produced with different active components such as multistriatin and methylheptanols depending on the species, sex and maturity of the beetles involved. These pheromones can act in combination with chemicals released from the host to direct further beetle attack towards the less heavily colonised areas of the same trees, or to other trees (Grove 1983), thus assisting in the spread of the disease.

The predominant elm in Scotland is the Wych Elm, regarded by some as the only species native to Britain (Gibbs 1974). It is relatively unattractive to bark beetles compared to the English Elm, and this may partly explain the slower rate of disease transmission in Scotland. Perhaps more important however is the size and distribution of the elm population in this country. Grieg and Gibbs (1983) estimated that there were only seven million elms over 6m height in the whole of the north of Britain before the present epidemic. Even though their distribution was limited to river valleys and low land, as elms seldom grow on land over 250m above sea level, there was thus a tendency towards lower densities in Scotland than in the rest of Britain where there were more elms. Also, the genetically homogeneous populations common in southern England were generally not found. The Wych Elm differs from the other British species in that it usually reproduces by seeds rather then vegetatively. In England, many English and Smooth-Leaved Elms were planted in hedgerows, and when these reproduced by root suckers, the result was a row of trees all genetically identical, connected together via a linked root system, and thus more susceptible to infection by Dutch elm disease transmitted via the roots than individual Wych Elms, even when these grew in close proximity to each other.

(b) The Pathogen

The discovery of the cause of Dutch elm disease is attributed to Dutch scientists (hence the name) who pioneered research in the 1920s into an epidemic affecting trees in Europe and North America. They established that the disease was caused by a microscopic ascomycete fungus now called *Ceratocystis ulmi* (Buisman) C. Moreau (*Ophiostoma ulmi* (Buisman) Nannf.), which grows in the living tree mainly in a yeast-like form and is transported in the sap. The effects induced by this pathogen are complex and as yet not fully understood, but recent research has shown that it is the detrimental effect of the fungal metabolites on the physiology of the tree that leads to the wilt syndrome and necrosis characteristic of Dutch elm disease (Scheffer 1983). C. *ulmi* produces a number of cell- wall degrading enzymes and phytotoxic compounds, including cerato- ulmin and glycopeptides which act mainly on the parenchyma cells next to the water conducting xylem vessels of the tree. They release cell wall components which provide a source of nutrients for the fungus and promote its growth, and this, in conjunction with the deposition of cell debris in the vessel cavities, impedes water transport throughout the tree. Cell outgrowths called 'tyloses', which are produced by the host to try and confine the extent of the infection, also tend to block the vessels so that eventually the passage of water from the roots to the leaves is inhibited, and wilting and die-back occurs. The blocked vessels appear as an outer ring of darkly stained dots in a cross section of the wood.

The severity of symptoms is influenced by a number of factors such as genetic make-up, vigor, and age of the tree. For example, more resistant elm species have been shown to differ anatomically from more susceptible ones in the size and distribution of vessels, and to demonstrate faster tylose growth (Elgersma 1983), so that the spread of the pathogen is hampered. Environmental factors such as nutrient status, soil condition and temperature are also important (Gibbs 1978), as is the time of year that infection takes place (early infection frequently leads to early death), but the over-riding factor affecting the severity and distribution of the disease is the virulence of the pathogen.

It is now recognised that there are two strains of the *Ceratocystis ulmi* in Britain, and that one is more virulent than the other. Called the 'aggressive' and 'non-aggresive' strains, they were first identified in the late 1960s when, with the development of a new epidemic of Dutch elm disease in southern England, trees began to die at a faster rate than before (Gibbs and Brasier 1973). In the years since 1927 when the disease was first identified in Britain, most infected trees had recovered, and only 10-20% of the total elm population died. With the new strain however, affected trees often died within one growing season. Investigations by the Forestry Commission found that the aggressive strain had been introduced into the country on diseased logs of rock elm *(U. thomasii)* imported from Canada (Brasier and Gibbs 1973), but by the time the serious nature of the new epidemic was apparent, it was too well established for any effective control programme to be organised. The aggressive strain did not arrive in Scotland until the mid-1970s, but from then its effects were similar to those in the south, i.e. accelerated death rate amongst infected trees. The two strains can now be distinguished in culture, and one explanation for the virulent nature of the aggressive train is its fast growth rate.

(c) The Vector

Dutch elm disease is mainly transmitted by elm bark bettles, three species of which are present in Britain, *Scolytus multistriatus* (Marsham), S. *laevis* (Chapuis) and S. *scolytus* (Fabr.), although only the latter occurs in Scotland. The beetles are specific to elm trees and their complex life cycle is linked with dead or dying elms, since they are unable to colonise or reproduce in healthy trees (Kirby et al1982). Trees selected for breeding must already by weakened and so those infected with the disease provide an ideal host.

The life cycle of *Scolytus* beetles is shown in Figure 2. Once the beetles have emerged from moribund elms during the late spring / early summer, they spend some time feeding on the bark of healthy twigs, particularly the nutritious cambium layer. Although this behaviour was thought to be a prerequisite for sexual maturation, recent research suggests that such feeding is instead initiated by the need to obtain water and nutrients (Kirby and Fairhurst 1983). The beetles tend to bore preferentially into the twig axils or crotches, and in doing so they penetrate the xylem. If they have come from trees infected with the disease, they will pass fungal spores into the vascular system of the healthy tree. When the beetles have fed, they search for moribund trees in which to breed. These trees often become badly attacked because pheromones which induce aggregation are produced by the pioneer beetles. After mating the females lay their eggs in galleries tunnelled into the sapwood, and when these hatch, the larvae also feed by burrowing into the softwood. The symmetrical breeding galleries subsequently produced provide ideal sheltered sites for the production of fungal fruiting bodies, so that when, after pupating, the young beetles eventually leave the tree as adult insects, their bodies are covered with fungal spores. These emergence flights are often synchronised and the tree may appear to have been peppered with shot because of the large number of small round exit holes.

A number of factors are known to influence the behaviour of elm bark beetles and therefore to indirectly affect the transmission of the disease. For example, colonisation of host trees is sometimes inhibited by a saprophytic fungus *Phomopsis oblonga* (Webber 1981), which competes for space with the beetles in the breeding galleries and prevents development of larvae. Massive colonisation of elm bark by *Phomopsis* has mainly been observed in Wych Elm, and according to Webber (1981) it is more common in the north of Britain, which may have contributed to the initial lower infection rate in Scotland. Similarly, recent research identified *Pseudomonas* bacteria as being anatagonistic towards *Ceratocystis ulmi* in elms, and suggested that it could be used as a form of biological control (Scheffer 1983).

Beetle emergence and flight are also very much affected by weather conditions (Crowson 1976). They seem to be restricted to days when temperatures are between 15 and 31°C, with the optimum temperature being 21 °C (Water 1981), and directional flight is inhibited when winds exceed 5m/s. Thus adverse weather conditions which provide sub- threshold flight temperatures or excessive winds prevent beetles from locating and colonising elms and may result in insects' death from dessication within three days. Since such adverse weather is more common in the north of Britain, the effect of climate on the dispersal of bark beetles seems to have been important in restricting the rate of spread of the disease in Scotland. Warm weather enhances the spread of the disease, since a mild spring and summer not only provide optimum flight temperatures, but also allow the emergence of a second brood of beetles within the same season. Thus, the effect of a series of warm summers in Scotland in the 1970s was to spread the beetles and the disease further north than previously (Greensill 1977), and ultimately make some form of control necessary if Scottish elms were to be conserved

CONTROL OF DUTCH ELM DISEASE

Research carried out within the last ten years has not only increased our knowledge of the ecology of the disease, but has also had important implications for control policy.

The basis of control methods is **sanitation felling** by which infected elms are cut down and the bark destroyed to eliminate the breeding grounds for the beetles. This technique has been tried in many countries over the years, and has met with varying degrees of success, e.g. in the United States (Burdekin 1979); in Britain (Greig and Gibbs 1983); and in the Netherlands (Water 1983). It is now clear that for sanitation felling to be effective, all diseased elms within a region have to be removed immediately the disease is identified. This is virtually impossible to achieve in practice, but if the majority of infected elms are felled, the rate of spread of the disease can be slowed considerably. Certainly, the most successful sanitation programmes have been those where trees were inspected regularly and diseased elms were removed promptly (Greig and Gibbs 1983), and this was most easily achieved when the elm population was geographically isolated from sources of new infection. Sometimes it is possible to save trees showing only very slight symptoms by pruning out the diseased branches, and, where practicable, spread of the disease between adjacent trees via the roots can be halted by trenching to sever the root connections. Sanitation felling is expensive, e.g. the Dutch spent £1.5 million per annum (Spinks 1986), but the technique has proved cost effective in many areas since, in its absence, many more dead elms would have to be removed for safety and aesthetic reasons (Bliss 1981).

Sanitation felling can be supplemented by **tree trap techniques** which attempt to artificially manipulate the aggregation behaviour of the elm bark beetles. *Scolytus* species are naturally attracted to elms by chemical volatiles called 'pheromones' produced by beetles when they bore into elm bark. The active components of these pheromones have been identified as methylheptanols (Blight 1980), and it is now possible to formulate baits for beetle traps using natural or synthetically produced pheromone chemicals. Trap techniques are useful in the monitoring and surveillance of beetle populations, but can also be used to suppress their numbers as shown at New York State University (O'Callaghan and Fairhurst 1983). They prevented reproduction of *Scolytus multistriatus* beetles by attracting them to elms which had been killed with the arboricide, cacodylic acid. Their broods fail to develop in the treated areas, possibly because of the rapid decline in bark moisture levels. Unfortunately, tests have not been so promising with *Scolytus scolytus,* the species present in Scotland, because their flight behaviour is not so strongly mediated by pheromones, and so the main use of the technique in this country would be in the monitoring of beetle flights.

Insecticides can be used to control the beetle before it introduces the fungus into the tree. The insecticide DDT was used extensively for this, ut was shown to have adverse effects on wildlife. Methoxychlor was substituted after DDT was banned, but since it is highly toxic to aquatic life, its widespread use is not recommended (Scott and Walker 1975).

In order to prevent infection by the fungus, individual trees can be injected with fungicides, the most commonly used being 'Lignasan: (carbenadzin hydrochloride). It is expensive because each tree has to be injected annually in order to maintain the correct dose throughout the canopy, and administering the high concentrations and volumes needed can be damaging to the tree. Also, it can only be considered as a preventative measure. Another common fungicide is 'Ceratotect' which is claimed to cure Dutch elm disease, provided it is injected into the tree in the early stages of infection. It has the advantage that it only needs to be injected every three years. Recently Dutch scientists have developed other fungicides including fenpropimorph, which can be easily administered by injecting into the roots or trunks of infected elms (New Scientist 1986). They inhibit the biosythesis of the fungus by preventing its conversion from the relatively dormant phase to the more dangerous mycelium phase. Research is continuing to develop slow release fungicide 'pills' which could be implanted into the trunks, and would be more cost effective than regular injections.

Forms of **biological control** which have been investigated include the effect of the fungus *Phomopsis oblonga* which prevents the development of eggs laid in elm bark (Webber 1981), and of the bacterium *Pseudomonas* spp. which act antagonistically towards *Ceratocystis ulmi* (Scheffer 1983). Also woodpeckers and other birds are natural predators of the bark beetle larvae, and it has been suggested that they could be used as a method of suppressing insect populations (Burdekin 1979). As yet it is not clear whether any of these methods could be successfully manipulated to control the disease.

Resistant species of elm have been developed over many years such as the 'Commelin' and 'Groenveld' elms planted extensively in the Netherlands in the 1960s, but most have proved to be susceptible to the aggressive strain of the disease (Heybroek 1988). The most recent strains have been developed from elms from Asia where *Ceratocystis ulmi* is thought to have originated, and these are the most promising. *Ulmus Sapporo'* Autumn Gold' is now widely available in Britain and the United States, and although expensive, its cost is going down as it becomes commonly used. However, its appearance is very different to the indigenous British elms, and so it is not really a satisfactory substitute.

Many of these methods have been used in Central Region.

DUTCH ELM DISEASE IN CENTRAL REGION

Prior to the 1970s, the non-aggressive strain of the *Ceratocystis ulmi* fungus caused few problems in Central Region. Those elms that did become infected usually recovered. However, by the mid-1970s, the aggressive strain had arrived from southern England, probably transported on diseased timber. The disease was readily spread to the susceptible English elms in the area, especially those along the Hillfoots of the Ochils, by the elm bark beetles known to occur in the Region. (One of the reasons for the designation of Abbey Craig as a Site of Special Scientific Interest was because it was the most northerly recorded incidence of *Scolytus* spp. in Britain). Soon afterwards the disease spread amont the larger population of Wych elms, and many trees began to die.

In 1977 the Regional Council set up a team of three inspectors as a Manpower Services Commission Project. Their brief was to patrol the countryside, to identify outbreaks and to persuade landowners to fell and bum diseased trees. Nearly all landowners co-operated with this policy, and the spread of the disease was slowed considerably. A programme of amenity tree planting was also promoted in conjunction with derelict land clearances. But by 1980, the disease had become so widespread that sanitation was only possible near major centres of population. This change of policy was endorsed by the Forestry Commission, who co-ordinate the disease control work of Local Authorities.

Between 1980 and 1982 the disease was contained and urban areas had only limited outbreaks. However, the number of elms lost in the surrounding countryside rose steadily, and it became increasingly difficult to prevent infection and death. Stirling and Alloa were within range of the beetle population of the Hillfoots, and there were several deep glens where sanitation felling would have been impossible. Similarly, Falkirk was close to heavily diseased elm woodlands in the Lower Carron Valley. Replacement planting with common deciduous trees including oak, beech, birch and ash, was accelerated to offset these losses. By 1982, the only area where the disease could be slowed down by sanitation felling was Boness, where the woodlands which dominate the hillside behind the town were relatively free of disease.

At this time, some of the control techniques described above were tested, one of the most successful being the first Scottish trial of the fungicide Ceratotect. There were two test sites. The first was a Weeping Elm *(Ulmus glabra)* in the grounds of the Regional Council offices at Viewforth. The treatment was successful for three years, as promised by the manufacturers, but in the fourth year, the tree contracted the disease and died. The other trees tested were along the River Forth, downstream of Stirling Bridge. Two of the large English elms injected are among the few healthy elms remaining in Stirling.

Figure 3 Local elm tree beginning to succumb to Dutch elm disease and showing the characteristic yellowing of leaves in summer (arrowed).

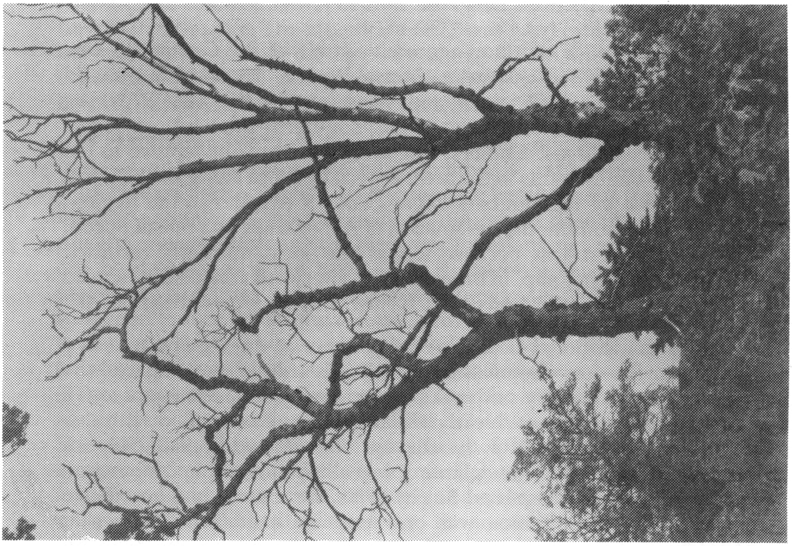

Figure 4 Dead Wych Elm.

Figure 5 Mature elms at Riverside, downstream of Stirling Bridge. They were injected with the fungicide 'Ceratocect' in 1982 and remain healthy in 1988.

Figure 6 Dead elm at Pitt Terrace, St Ninian's Road, Stirling.

In 1983, the *outbreaks* in Boness became more serious, possibly because the disease was increasing in the Avon Valley, in Lothian Region, and across the River Forth in Fife. Replacement tree planting however, did continue and is still carried out today, and an advice service for landowners has also been maintained by the Regional Council Planning Department. Landowners are now advised to carry out felling on the grounds of safety rather than disease control, and injections are only recommended if the tree is considered important enough to warrant a continuing commitment to expenditure. The most important advice is to carry out replacement planting using a mixture of deciduous or broadleafed trees.

In 1987, just *such* a replacement tree planting campaign was mounted by Bridge of Allan Community Council. It was intended to counter the losses of hundreds of diseased trees from the woods around the village. In 1985-86 Stirling District Council's arborist and his team had felled 110 large elms over ISm, 162 medium sized trees, and 126 small trees under 9m in the woods around Bridge of Allan owned by that Council. In 1987-88 they felled 225 trees in Mine Woods, 50 in Westerton Wood, 135 on Abbey Craig, 172 in the Allan Bank Wood and 23 in the Allan Vale Road area. The tree planting campaign, conducted with the help of school children, raised over £1,000 from the local community, and the Community Council, arborist and rangers were subsequently able to plant several hundred young replacement trees in Mine Woods and nearby areas.

CONCLUSION

Dutch elm *disease* has continued to infect and kill trees in the Central Region of Scotland over the last ten years, so that now few healthy mature elms remain. Unfortunately, much of the recent research into the ecology and control of the disease has come too late to save trees in this Region, although the programme of sanitation felling did achieve the objective of slowing down the spread of the disease, and allowed time for some replacement planting to take place. We have learnt that sanitation can only succeed in containing the disease where the area involved is isolated from new infection, and monitoring is vigorously pursued. In Scotland, the only 'defensible area' where sanitation felling continues are in Edinburgh, Dundee, and parts of Glasgow.

In Central *Region* the disease is now considered to have run its course, and the number of cases of infection is decreasing as there are so few mature elms left. The number of elm bark beetles has also declined due to lack of hosts. There is some evidence of natural regeneration of elms from the stumps and roots of diseased trees, some of which have produced vigorous suckers, and a proportion of these may survive, since the elm bark beetle cannot breed in trees of narrow girth. But we cannot rely on natural regeneration to replace those trees which have died, especially since there are now few places where suckers will be allowed to grow because of grass cutting practices, stock grazing, ploughing, and heribicide use. The only effective course of action to restore the losses is to continue with an extensive programme of tree planting with a mixture of native tree species (five as a minimum) so that any future diseases will not result in such a severe loss as caused by Dutch elm disease.

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Authors/Reviewers Addresses

Angus, David, 122 Henderson Street, Bridge of Allan.
Ballantyne, G. H., Branksorne, 193 Nicol Street, Kirkcaldy.
Corbett, L., Forth Naturalist and Historian, University of Stirling.
Elliott, B. J., Department of Education, University of Stirling.
Harrison, S. J., Department of Environmental Science, University of Stirling.
Henry, C. J., Department of Psychology, University of Stirling.
Muirhead, Andrew, Stirling District Libraries, Springkerse Estate, Stirling.
Neiland, Ruth, Department of Plant and Soil Science, University of Aberdeen.
Shaw, John, Royal Museum of Scotland, Queen Street, Edinburgh.
Shepherd, J. W., Planning Department, Central Regional Council, Viewforth, Stirling.