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Flooded Gum (*Eucalyptus rudis*) Decline in the Perth Metropolitan Area: A Preliminary Assessment

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Preface and Acknowledgements

This study was undertaken during September - November 1999 while Roger Clay was on Professional Experience leave from the University of South Australia, and was visiting the School of Environmental Biology at Curtin University of Technology.

The original intention of the study was to collect and compare canopy invertebrates from healthy and declining flooded gum trees to determine if there was any association between decline and the types and numbers of invertebrates present on the trees. However, after preliminary enquiries, it was quickly realised that other types of survey work were needed before canopy collections could begin and, in fact, these surveys took up most of the visit. Canopy collections were done shortly before Roger Clay left Perth and all material had to be taken to Adelaide where it is still being processed.

Much of the work done in Perth would have been impossible without the help of volunteers and others. Most importantly, we would like to thank Barbara Dundas of the Guildford Catchment Group for her support and work throughout most of the project and for her ability to organise a wide variety of assistance. There is no doubt that we would have accomplished much less without her help.

We would also like to thank the managers and staff of Whiteman Park for their help in locating and sampling trees in the Park. In particular, we would like to acknowledge Harry Gratte, David Bright, Jason Dearle and Terry Verney for their help. Valuable background information was provided by Robert Powell, Alan Wills and Tom Burbidge of CALM. Discussions with Dr. Elaine Davison of Curtin University were most useful, and we would also like to thank Dr. Brian Heterick and Agustine Dorinila, both of Curtin, for their help with methodology. River survey work upstream from Guildford was made possible by the SEC, and particularly Trevor Greasley and Gordon Munday. Thanks also to Alex Lennox of Bassendean Council.

A group of volunteers assisted with the canopy sampling at the Guildford site. Thanks to Ben Derre, Daniel Millan, Vanessa Yeomans, Mike Grasby, Barbara Dundas, Jes Dorricott, Rebecca Graham and Daniel Majer, and also to Nicky and Des Bushell for use of their home to process samples.

Drs. Ian Abbott and Janet Farr were kind enough to read an earlier draft of this report. We thank them for their helpful suggestions.

This report will not provide all results of the canopy invertebrate sampling. Processing these samples has been very time consuming and is still not complete. We have decided that it is more important to make information from our surveys available now, when it will, hopefully, still be of use, rather than wait until all results are finalised.

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Summary and Recommendations

This report presents the results, conclusions and recommendations of a study of decline (dieback) in flooded gum *(Eucalyptus rudis)*, conducted in the Perth metropolitan area in spring and early summer of 1999. This is a preliminary report which does not provide the complete results of canopy invertebrate sampling, but is complete with respect to all other phases of the study.

Dieback is characterised by progressive decline in tree health, which includes cycles of defoliation and regrowth. Over time, a tree's reserves become depleted and the regrowth phase is likely to become less vigorous. If the causal factors continue to operate, tree death may eventuate, although this may occur some years after the first round of defoliation is observed.

This study found dieback to be widespread in 1999, however its occurrence was very variable and we failed to discern any pattern in the distribution of tree decline. Most trees that were affected had a high proportion of discoloured leaves and were shedding leaves. In some instances we observed trees that were completely defoliated, and in others we observed regrowth. We did not observe any trees that we considered to be dead. We concluded that the dieback was a recent phenomenon, which was in its first cycle of defoliation.

Casual, and more systematic, observation showed that there were higher densities of lerps (the shelters of sucking insects called psyllids) on leaves of declining trees than on healthy ones. There also was an association between the type of groundcover under the trees and tree condition. Healthy trees occurred in disproportionately large numbers over groundcovers that contained some native plant species, as opposed to weedy or mown grass groundcovers. We suggest that the more natural groundcovers provide more food and shelter for the predators and parasitoids of foliage feeding insects, and therefore assist in natural control.

Apart from the association with lerps, no association was found between dieback and other types of biological damage, e.g. insect galls, leaf chewing, leaf mining and bacterial/fungal attack. This was shown both by subjective assessments of trees, and by measurements of leaf area loss.

Canopy invertebrates were extremely abundant, but highly variable from tree to tree, regardless of tree health or the location of the trees. Only one invertebrate group, psyllid nymphs were in significantly higher numbers on declining trees than healthy ones. For all other types of invertebrate groups there was no significant difference between healthy and declining trees. However, the extreme tree to tree variability, and the small sample size, made it difficult to show significant differences.

A large number of physical and biological factors have been suggested as the primary cause of the flooded gum dieback in Perth. However, it must also be recognised that no single factor may be involved, and that interactions between two or more factors may be responsible for triggering decline. Considering the complex nature of tree decline, it is not surprising that this preliminary study was unable to determine the primary cause(s). Nevertheless, we can suggest that some factors are less likely causal agents than others. We do not believe that changing watertables, either rising or falling, are likely agents, nor do we believe that increasing salinity is a likely cause in the Perth area. Nutrient enrichment of waterbodies, a common phenomenon in Australia, may be a causal agent by contributing to higher concentrations of nutrients, particularly nitrogen, in tree foliage. These elevated concentrations may, in turn, encourage the outbreak of foliage feeding insects, for example, the high psyllid densities that we have observed. However, it must be stressed that we found no significant difference in nitrogen levels between healthy and declining trees, although there were significantly higher phosphorus levels in declining trees than in healthy ones.

Our examination of some possible biological causal factors, has made all very unlikely agents, except for psyllid insects. These have a very clear association with declining trees, and are undoubtedly contributing to the decline in tree health. Whether, or not, psyllids are the primary cause of the dieback is another matter, however. Some researchers (for example, White 1986) believe that infestations by psyllids, and other insects, only occur when trees are under stress, and that it is the factors creating stress that are the primary causal factors. Other researcher workers (for example, Morgan 1984) do not support this theory, and suggest a primary role for insects. We were unable to distinguish between these two possibilities on the basis of our results.

We expected that most, if not all, trees observed to be in decline in 1999 would have produced epicormic growth by the time of writing of this report. Casual observations in spring, 2000 support this expectation. The critical question is whether this will lead to permanent recovery, or whether there will be another cycle of defoliation and epicormic growth, thus establishing the typical pattern of dieback observed in other eucalypt species in other parts of the country. The answer to this question requires a sophisticated understanding of the causal factor(s), and we do not have that understanding.

In the short-term, there are measures that may control psyllid numbers on individual trees, but broad-scale control is impractical. Control on individual trees may be achieved by injection into the trunk of systemic insecticides but, of necessity, an experimental approach must be adopted for such treatment. Experimentation with fertiliser application may also have some effect.

In the longer-term, since psyllids are an important contributing factor to flooded gum decline, there are some strategies that could be implemented to reduce their impact.

- If trees can be located that are resistant to decline, seeds for plantings should be harvested from resistant trees in preference to those of susceptible trees.
- Apart from this limitation, seeds should come from a variety of sources to maintain genetic variability.
- Single-species plantings (monocultures) should be avoided..
- Re-establish native shrubs, herbs and grasses in the understorey of established flooded gum stands and in plantings.

Finally, further monitoring and research are required to determine the cause of flooded gum decline, and to examine ways of alleviating it. We have made a number of suggestions for further study.

1.0 Introduction

This is a preliminary report of a study conducted between September and November 1999 in Perth. The study was initiated because of widespread concern about the health of flooded gum (*Eucalyptus rudis*) trees in the Perth area. The trees are a conspicuous and integral component of Perth's wetlands and watercourses, and add greatly to the aesthetic appeal of these areas. The decline of trees during 1998 and 1999 had been obvious in Perth, and had generated much comment, including speculation about the cause(s). However, there had been little systematic study of the trees, nor did there appear to be clear reasons for their decline, and thus this study was initiated.

The study is not yet complete and invertebrate processing continues in Adelaide. The purpose of this preliminary report is to provide initial results and conclusions to Catchment, Landcare and other conservation groups, and is also aimed at Local Government and interested members of the public. The value of this information will be compromised by further delays in its publication.

This report provides brief reviews of flooded gum and dieback. It also provides an outline of the methods used during the different phases of the study. Initial results and conclusions about possible causes of dieback in flooded gum are given and, flowing from these, recommendations and suggestions for further study are made.

1.1 Flooded gum

Flooded gum is restricted to the south-west corner of WA and typically it can be found along watercourses, on floodplains and around wetlands. Mature trees usually have large spreading canopies and are very picturesque. The species occupies similar habitats to those occupied by river red gum (*Eucalyptus camaldulensis*) in much of the rest of the country. In the southern parts of its distribution, flooded gum has rough dark bark on the trunk and lower branches, making it easily distinguishable from the smooth light-coloured bark of river red gum (Gardner 1987). In the northern parts of the range of flooded gum, its bark is much smoother and the distinction between the two species is much less obvious (Gardner 1987). Also, young trees are very difficult to distinguish because the barks have not differentiated and there are no fruits to compare. (This is an important point because planting of river red gum in the Perth area is not uncommon.) The two species are similar enough to hybridise naturally where their ranges overlap (south of Geraldton).

Abbott (1999) reports that flooded gum timber is of little commercial value and, consequently, little study has been done on the species. We know little of its ecology. Abbott (*ibid.*) confirms considerable anecdotal evidence that the trees are subject to significant insect attack, to the point that the trees may have many brown leaves and sparse foliage. The trees have also been observed to have an unusually large number of visits from birds, in terms of both species and individuals (*pers. comm.* Prof. Harry Recher, Edith Cowan University). These observations suggest an important ecological role for flooded gum.

1.2 Dieback

Dieback (also referred to as "rural dieback") is an important conservation problem throughout many rural areas of Australia and has been studied quite extensively on the New England Tablelands of NSW. As used in this report, it should not be confused with the well known "jarrah dieback" caused by *Phytophthora cinnamomi.*

Podger (1981) indicates that the term "dieback" has been used in various ways. In this study, the term is applied to the whole tree and in this sense, indicates "progressive general deterioration" which may end in tree death (Podger 1981). The typical progression for flooded gum observed in the Perth area, was some leaf discoloration which steadily affects more leaves and also becomes more severe on individual leaves resulting in them becoming completely brown. Brown leaves begin to drop from the tree causing obvious canopy thinning. Thus trees may pass through a phase when all leaves are brown, but then progress to the point of complete leaf loss. At this stage the tree appears to be dead, but it is very unlikely that this is actually the case. Most eucalypt species have special buds (epicormic buds) under their bark; a characteristic that probably evolved as an adaptation to fire. Some time after defoliation of branches, these epicormic buds give rise to multiple shoots which produce new leaves. During the study, this stage was observed on flooded gum trees that were assumed to have been defoliated in 1998. This was the full extent of the progression observed during this study.

If the causal factors of the dieback persist, or recur, another round of leaf discoloration and drop may be triggered Again, the tree is likely to respond with epicormic growth, but perhaps not as vigorously as the first time This cycle can be repeated a number of times over a period of years, but will probably be characterised by a weaker and weaker recovery in successive cycles as the tree's reserves become depleted. Tree death is the likely endpoint. It has been commonly observed that dieback is very "patchy"; that is, dieback trees can be in close proximity to healthy ones. One possible reason for this may be genetic differences between trees in their resistance/tolerance to the factors causing decline.

Dieback is a complex and progressive phenomenon for which a large number of causes, both biological and environmental, have been proposed. For example, in their book on dieback, Heatwole and Lowman (1986) review the possible roles of land clearing, fertiliser application, soil erosion, overstocking with domestic animals, salinity, drought, flood, changes in watertables, fungal diseases and insect attacks. It is unlikely that dieback can be attributed to a single causal factor, although White (1986) reviewed a number of cases of dieback and proposed that changes in weather patterns initiated the dieback progression. It is also unlikely that the same group of causes are operational in different locations and/or on different tree species. The complexity of dieback is perhaps best epitomised by a sentence from Heatwole and Lowman (1986) *There is no simple, direct answer to the question 'what causes dieback?'*.

Insect attack is often associated with dieback and is usually very obvious. For example, as early as 1976 Hopkins reported extensive defoliation of flooded gum caused by psyllids (see section on psyllid damage, below). However, it is suggested by Morgan and Bungey (1981) that trees will usually recover from psyllid attack and death will only occur if the regrowth is subsequently attacked by other types of insects. Duggin (1981) found extensive defoliation by Christmas beetles, leaf skeletonisers (caterpillars) and other beetles on three species of eucalypts in New England and Abbott (1999) implicated a leaf miner (another caterpillar) in flooded gum dieback. There have also been reports of more complex interactions, which involve birds and insects, where it is suggested that the dominance of aggressive bird species eliminates species of birds that would otherwise feed-on, and help to control, foliage insects (Loyn 1987; Stone 1996).

The obvious association between insects and dieback does not necessarily mean that insects are the primary cause of the dieback, and there has been much speculation and research about the causes of insect (particularly psyllids) outbreaks on trees. It is beyond the scope of this report to review the arguments and ideas about these outbreaks. White (1986) provides an overview of the theories and ideas he has developed over many years and Morgan (1984) critically reviews White's ideas and compares them with his own, and those of other authors. Briefly, White emphasises the importance of water stress in the trees and an associated increase in available nitrogen, which results in an elevated survival rate for young psyllids. In contrast, Morgan and other authors believe that there should be good soil moisture and unstressed leaves, and emphasise the growth cycle of the trees. For example, trees should not be flowering or fruiting to any marked degree, and leaves of the appropriate age class and/or with low levels of feeding inhibitors should be present (Morgan 1984). A lack of, or inefficient, natural controls (predators and parasites) of the psyllids is also considered to be important, as is the fact that the trees occur in "uneven-aged monocultures" (Morgan 1984).

In summary, a large number of biological and environmental causes have been proposed for dieback, but there is no consensus as to a primary cause, or even if there is a single cause. Individual causes, or combinations of them, are likely to be operable in different circumstances. Dieback does not necessarily affect all trees in an area, and can be quite patchy. Proliferation of plant feeding insects is common, with associated leaf death and canopy thinning. Recovery will almost certainly occur through epicormic growth but, if the causal factors persist, further episodes of canopy thinning and recovery are likely. The end point of a number of such episodes is likely to be tree death. Readers who would like more information are referred to *Dieback* by Heatwole and Lowman (1986).

1.3 Flooded gum and dieback

Flooded gum dieback may be new to the Perth area, but has been observed in other parts of the south-west for many years. As mentioned above, Hopkins reported dieback in 1976. Curry (1981) suggested that the psyllid *Creiis periculosa* attacks flooded gum in winter and spring causing defoliation, but that infestations rarely occur in consecutive years on the same trees. Thus, recovery should be possible. Kimber (1981) stated that crown dieback in flooded gum was not uncommon and was due to jarrah leafminer (*Perthida glyphopa*) infestation which, unlike the psyllid attacks, can occur in successive years (see Section 1.4.1 for more recent information on this leafminer).

In a comparison near Manjimup of eight native tree species and the degree of insect and fungal attack, it was found that flooded gum had 22.6% of its leaf area affected; a percentage only exceeded by jarrah with 23.6% (Abbott *et al.* 1993). Leaf mining and chewing were the most prominent type of insect damage on flooded gum. Five of the species had <8% of their area affected, indicating that jarrah and flooded gum seem to be particularly susceptible. Flooded gum sustained the highest leaf area loss to *Mycosphaerella* fungus (12.5%). In the same study, it was shown that only 47% of flooded gum leaves were still alive after 12 months. This percentage is much lower than for any of the other species. Flooded gum also had the highest concentrations of the three nutrients measured (nitrogen, phosphorus and potassium). It is important to note that the study was done on coppice foliage, described as "the common bushy hemispherical shrub to sapling form" (Abbott *et al.* 1993). No quantitative studies have been done to determine if similar degrees of damage are experienced by mature flooded gum trees, however, subjective assessments suggest that damage is similar (*pers. comm.* Ian Abbott, December, 2000).

Yeomans (1999) studied flooded gum decline along the Preston River near Donnybrook, a location where decline has been observed for some years. She found that the degree of decline decreased as one moved upstream. This decline was suggested to be due to the jarrah leafminer (*Perthida glyphopa*)(or a related sub-species), but Yeomans found that the leaf area mined and the number of mines did not differ significantly between upstream (less decline) and downstream (more decline) sites. In contrast, there were far more lerps of the psyllid *Creiis periculosa* (25 per leaf) downstream than upstream (< 1 per leaf). Loss of leaf area to chewing was significantly greater downstream than up. Damage due to skeletonisers and general leaf necrosis was minimal. Measurement of leaf nutrients showed that there was no difference in concentrations of nitrogen, phosphorus, sugars and starch between upstream and downstream sites.

Even though leafminer was the main suspect, Yeomans' (1999) study found no evidence to implicate leaf miner in flooded gum decline. Significantly higher leaf chewing damage and lerp numbers, associated with less healthy trees, need greater investigation, especially as they do not appear to be associated with higher concentrations of nutrients. Although the study examined a number of environmental variables, none seemed to be associated with decline. It was noted that a greater proportion of weed species occurred downstream, and there was also suggestion that changes in river flow and land use below a dam may be associated with decline.

Recently, Abbott (1999) has attributed decline in flooded gum trees near Dardanup and Kojonup to attack by a leafminer; closely related to jarrah leafminer. This leafminer was first recorded in the Perth area in 1897 (determined from herbarium specimens), after which it increased in abundance dramatically. He suggests that a change in fire regime, accompanying European settlement, may have been responsible

1.4 Eucalypts and insect pests

Because insects are usually associated with eucalypt dieback we have provided a brief review of the types of insects, and associated damage. No attempt has been made to write a comprehensive review and we rely heavily on a series of leaflets published by CSIRO entitled *Insect pests of eucalypts* (Farrow 1996). Although focused on south eastern Australia, the leaflets are useful in identifying types of damage and the group of insects involved, even though the specific insect species involved in Western Australia may not be the same. Each leaflet contains diagnostic photographs of damage and the insects. Information is also provided about host trees, insect biology and natural enemies of the insect(s). Noted here are types of damage that are likely to be found on flooded gum.

1.4.1 Leaf mining: Caused by caterpillars of moths of the genus *Perthida*. *Perthida glyphopa* causes extensive damage to jarrah trees, and a closely related species (Abbott *et al.* 1999) attacks flooded gum. The latter species was first recorded in the Perth area in 1897 and it has been more frequent on flooded gum than leafminer on jarrah (Abbott *et al.* 1999). Caterpillars create distinctive blotch scars (mines) as they feed between the two surfaces of the leaf. Caterpillars ready to diapause cut a neat, oval hole in the leaf and drop to the ground. In a comparison of damage to eight eucalypt species, Abbott *et al.* (1993) found considerable leaf miner damage on flooded gum, only exceeded by that on jarrah. As noted above, Abbott (1999) has attributed flooded gum decline to leaf miner.

1.4.2 Chewed leaves: A variety of insects, including weevils, other beetles, sawfly larvae and caterpillars, damage leaves along their margins or create irregular holes. Abbott *et al.* (1993) found considerable chewing on flooded gum, although it was not as severely affected as some other species, and Yeomans (1999) found an association between degree of leaf chewing and tree decline (see above).

1.4.3 Leaf skeletonising: Caterpillars of the moth *Uraba lugens* are probably the main cause of this damage, although other insects can also be involved. As the common name implies, young caterpillars feed on the leaf but leave the veins untouched. Older caterpillars eat the entire leaf, except the mid-rib and leave a ragged margin. Severe outbreaks have been reported to defoliate entire forests. Although we observed skeletoniser damage on flooded gum, it did not appear to be a major pest. This is borne out by the comparisons of Abbott *et al.* (1993); of eight eucalypt species studied, they found skeletoniser damage to be the least on flooded gum, and relatively minor compared to other types of damage

1.4.4 Leaf galls: These are irregular lumps and protruberances on the leaves. They may often be in rows on the leaves and be reddish in colour. They are usually caused by the larval stages of parasitic insects which induce abnormal growth in the leaves. The larvae live and feed in the galls. Sometimes, depending on the invading insect and the time of the invasion, the entire leaf may become a gall. We commonly observed leaf galling on flooded gum, but this did not appear to be an important type of damage. Abbott *et al.* (1993) also found only minor damage from leaf galling on flooded gum.

1.4.5 Stem galls: These are irregular swellings on stems which have a similar origin to leaf galls, although a different suite of parasites are involved. We observed occasional trees that were severely affected by stem gall, but usually there were no, or very few, galls.

1.4.6 Stem borer: Larvae of longhorn beetles, certain moth species and some weevils tunnel and feed in stems and branches. Bullseye borer, *Phoracantha acanthocera*, is particularly damaging in Western Australia and may attack trees under stress. The name bullseye comes from the distinctive appearance of the stem. The larva excavates a chamber surrounded by a circular groove under the bark. The entry hole is plugged with frass (larval excreta and other material). Bullseye borer is not usually found in large numbers in a single tree, and this combined with its feeding behaviour, make it unlikely that this borer could kill a tree (*pers. comm.* Janet Farr, December, 2000). Flooded gum at Gosnells and, to a lesser extent, at Waterford were affected by bullseye borer (*pers. comm.* T. E. Burbidge, Dept. of CALM). We observed some stem borer damage in flooded gum at Herdsman Lake, but only rarely elsewhere.

1.4.7 Psyllid damage Psyllids are small sucking insects which feed on plant sap in the leaves or young stems Depending on species, a psyllid can be free-living, or remain under a structure called a lerp, as it feeds and develops from a small nymph to an adult, winged psyllid. Lerps are formed from the nymph's faeces, which contain starches and sugars (White 1993, p.36) and can have a variety of shapes and forms, depending on species. Australia is noted for its high diversity of psyllids, and many are associated with particular species of eucalypts.

Although relatively few Australian psyllid species are capable of reaching outbreak proportions (Morgan 1984), outbreaks are not uncommon and can last for several years,. They have been studied extensively without consensus as to the cause(s) of the outbreaks (see Morgan 1984, and above). The feeding of some species causes the leaf in the immediate vicinity of the psyllid to discolour and die. If there are many psyllids, dead patches will combine and the entire leaf may die and then drop from the tree. Thus extensive defoliation can be associated with psyllid outbreaks.

The elongated, translucent lerps of the psyllid *Creiis periculosa* (Plate 1) were commonly seen by us on flooded gum; often in very high densities. This is a type of psyllid which appears to be capable of reaching outbreak abundances, and is also capable of causing leaf death. It has been implicated previously in flooded gum decline (Curry 1981; Yeomans 1999).

Plate 1. Lerps of the psyllid, *Creiis periculosa,* on flooded gum leaves.

2.0 Aims

The aims of this project were:

- To map the pattern of tree decline along a section of the Swan River;
- To investigate reasons for any observed pattern of decline;
- To examine possible causal agents of decline by comparing healthy and unhealthy trees; and
- To provide recommendations for future actions.

3.0 Methods

There were four phases to the study:

- preliminary survey;
- comprehensive survey along the Swan River;
- comparison of healthy and declining trees; and
- sampling of canopy invertebrates.

3.1 Preliminary Survey

Checks were made of some wetlands and riverbanks in the Perth area. The purpose of this survey was to gain a general impression of the extent and nature of the dieback. There was no attempt to be comprehensive or conduct a systematic survey. Subjective notes were made of tree condition and proportion of trees affected. Visits were made to Perry Lakes in Floreat, Churchlands, Waterford on the Canning River, Herdsman Lake, Neil McDougall Park in Como, and various sites along the lower part of the Helena River, including its confluence with the Swan River near Guildford.

3.2 Survey of Swan River

The purpose of this phase was to document the extent of dieback along the Swan from the Perth Central Business District (CBD) to upstream of Guildford and to determine if there were any associations between presence and severity of dieback and a number of environmental factors. An initial reconnaissance along the Swan by boat identified the locations of flooded gum (especially where the first flooded gums appeared upstream from the CBD), and provided an impression of tree condition.

A detailed survey was then done from Belmont Point (the most westerly occurrence of flooded gum on the Swan) to Mulberry Farm (opposite Guildford). Approximately 40km of riverbank was mapped. Access was either by bicycle or foot, with the exception of the river upstream from Point Reserve (opposite the confluence with the Helena River) which was surveyed from a boat. Use of the boat required a change to the way information was recorded and, consequently, it is not completely comparable with that recorded below Point Reserve. In some places fenced, private property extends to the river's edge and access was impossible. There was a small, inaccessible area east of Garvey Park (between Redcliff and South Guildford) and a much larger strip on the Ashfield/Bassendean side from Sandy Point Reserve to Point Reserve.

A data sheet (Appendix 1) was designed, trialled and, after modification, used to record tree condition and environmental factors in 100m strips along each bank of the river. Apart from identification and description of the area, the following information was recorded for each 100m strip:

- decline index - indicated the most common tree canopy condition in categories 1 to 5 (Appendix 1);
- tree mix - indicated the mixture of saplings, young and mature trees in categories 1 to 7 (Appendix 1);
- vegetation depth - distance, in metres, that the flooded gums extended from the riverbank;
- understorey/groundcover - recorded as categories 1 to 5 (Appendix 1) to indicate degree of disturbance;
- area size - usually recorded as 100m by depth of vegetation, but occasionally strips of 100m were impossible;
- use of area - recorded as categories 1 to 5 (Appendix 1); and
- backing land use - recorded in categories 1 to 9 (Appendix 1), to indicate use of the area contiguous with the flooded gums.

The data collected were summarised in two-way tables (categories of tree decline versus categories of one of the other variables). Data collected from the boat was treated separately because they were not comparable with those collected along the bank on foot. Data collected from the Helena floodplain were also treated separately because it was thought inappropriate to combine data from river bank strips with broad-area floodplain data. Possible associations in the riverbank data were checked for by using Chi-square tests. To satisfy requirements of the Chi-square test, categories sometimes had to be combined to ensure a large enough "expected value". Sample sizes in the other two groups of data were too small for statistical analysis. Consequently, the data were examined to identify any differences with the riverbank data.

3.3 Comparisons of healthy and declining trees

Fifty young trees, located at four different sites, were selected for this phase. The condition of trees was subjectively assessed and trees were then categorised as "healthy" or "declining". Because trees had to be inspected from the ground, it was impractical to survey large trees. Adequate visual coverage could only be guaranteed for young trees. Heights of the fifty trees were between 3 and 7m.

Twenty trees were located on the south-east corner of Herdsman Lake and 10 were located on flood plain south of the confluence of the Helena and Swan Rivers (South Guildford). Ten trees were located at each of two sites in Whiteman Park (these trees tended to be shorter than those at other sites). At each site, an equal number of healthy and declining trees were surveyed. Most of these trees had been planted, although some at Site 2 in Whiteman Park were natural recruits. Plate 2 provides a comparison of a healthy (Category 1) and a declining (Category 3) tree.

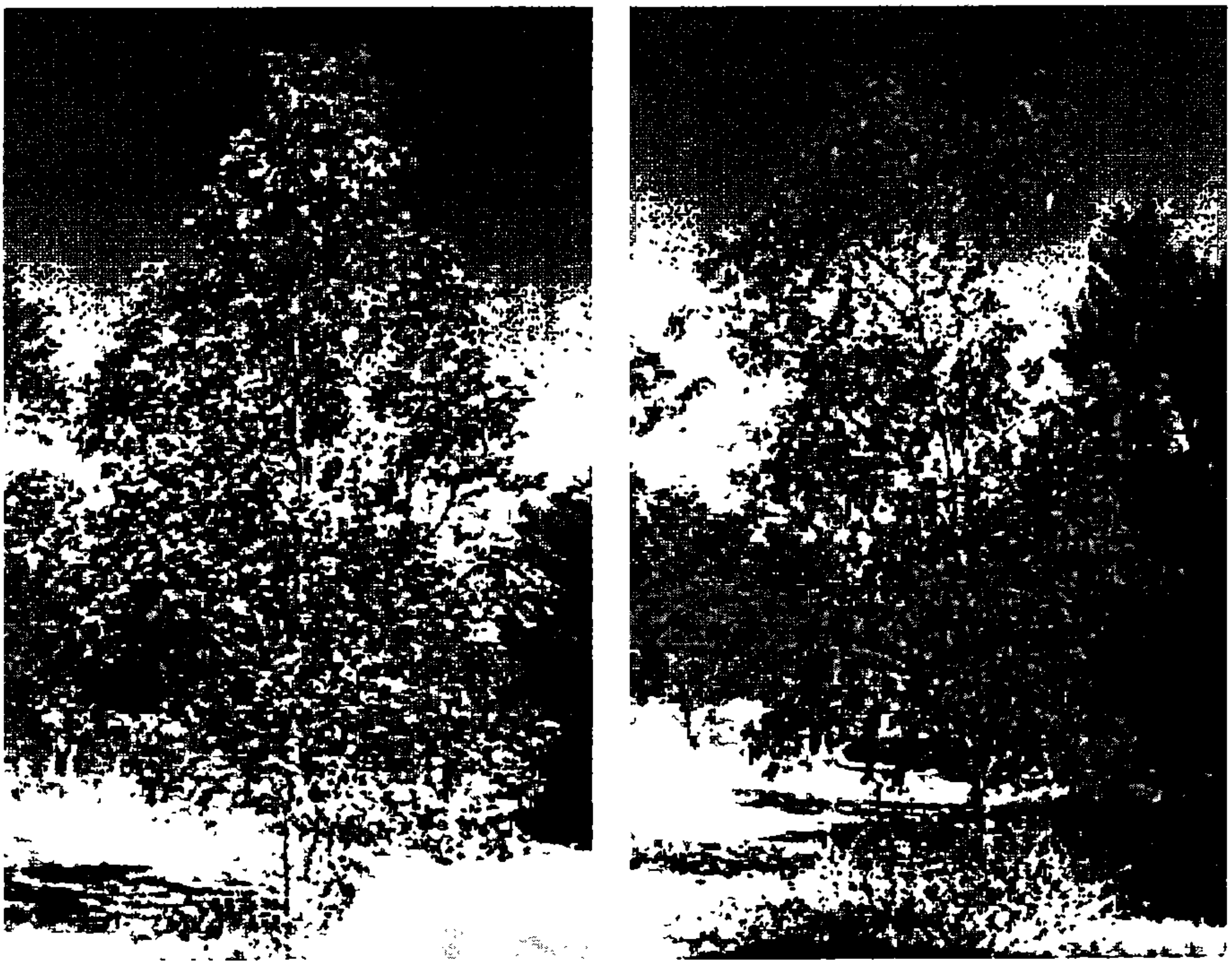

Plate 2. A healthy (Category 1) tree (left), compared to a declining (Category 3) tree (right) at the South Guildford site.

A data sheet was developed applicable to this and the next phase of the survey (Appendix 2). Each tree was inspected (using binoculars if necessary) and subjectively assessed for condition and degree of damage of various biological origins. The following information was recorded:

- tree type - either sapling or young;
- decline index - recorded in one of four categories;
- presence of lerps - three categories;
- degree of chewing insect damage - three categories;
- degree of leaf miner damage - three categories;
- presence of leaf blisters - three categories;
- presence of necrotic patches on leaves - three categories, but not always possible to record because browning of the leaves masked necrotic patches;
- presence of stem galls - three categories; and
- presence of stem borers - three categories.

Other columns ("Canopy Characteristics") on the sheet were not used in this phase of the work.

Regardless of site, trees were grouped into two-way tables (categories of tree decline versus categories of one of the other variables). Possible associations were checked for by using Chi-square tests.

3.4 Sampling of canopy invertebrates

The final phase was a more detailed assessment of thirty of the trees, mentioned above, located at the South Guildford and the two Whiteman Park sites. At each site five healthy trees and five declining trees were examined. Leaf samples were collected for nutrient analysis. The 'knockdown' technique was applied to each tree and all invertebrates were collected. Other leaves were collected so that the number of lerps per leaf could be counted, and areas affected by necrosis and leaf chewing insects could be determined precisely.

3.4.1 Nutrient analysis Ten undmaged leaves were removed from various positions on each tree for subsequent nutrient analysis, stored in paper bags and subsequently oven-dried at 72^0C to constant weight. These leaves were treated as one sample and were ground and analysed together for their content of nitrogen, phosphorus, potassium, sulphur, sodium, calcium, magnesium, copper, zinc, manganese, iron and boron. Differences between tree type and site, for each nutrient, were tested by analysis of variance.

3.4.2 Knockdown collections: Trees were selected on the basis of their health/decline, size and ease of access to all parts of the tree. For selected trees, heights to the top and base of the canopy were recorded, and canopy (foliage) density was subjectively assessed in one of five categories (Appendix 2). After clearing grass and weeds to create a flat surface, a 2m x 2m sheet was laid under each tree canopy. A motorised, backpack sprayer was then used to drench thoroughly all foliage overhanging the sheets. The spray consisted of a 0.2% solution of "Dominex" (a pyrethrin insecticide) in water. Trees were then left for one hour to ensure that all invertebrates were dead and had fallen to the sheet. Before sheets were folded-up, the foliage was knocked with a stick to dislodge any remaining, dead invertebrates. Five branchlets (20-30cm long) were removed from various locations on each tree.

3.4.3 Counting lerps: Each of the five branchlets taken from each tree was processed in the following way:

- starting from the tip of the branchlet, and ignoring obviously immature leaves, leaves 1, 3, 5 and 7 were removed;
- the numbers of intact lerps on both surfaces of each removed leaf were then counted;
- the total number of lerps for the four removed leaves of the branchlet was then determined; and
- the four leaves were then taped to paper for later area determinations.

When leaf area had been determined, lerp numbers were standardised to number per $10cm^2$. These standardised numbers, which were often small, were square root transformed and then used in an ANOVA to check for differences in lerp numbers between tree types.

3.4.4 Area affected by necrosis: The term "necrosis" was used broadly and included any type of leaf damage that had not actually reduced leaf area. Thus areas infected by fungi, other discoloured areas (possibly due to bacterial infection), leaf blister (probably due to invertebrate attack), skeletonised areas due to caterpillar feeding and areas mined by leaf miner were all counted as necrotic areas. The four leaves were assessed subjectively and collectively. According to the area of necrosis, they were placed in one of six categories by comparison with standard diagrams taken from Carnegie *et al.* (1994). The diagrams are reproduced in Appendix 3. Differences between tree types in their categories of necrosis were tested by contingency Chi-square.

3.4.5 Determinations of leaf area and leaf area loss Using a scanner, images of the four leaves from each branchlet were stored on computer The area of each group of leaves was then determined using a software package (Nih Image; version 1.62). In almost every case leaves had holes and/or had lost leaf margin due to insect attack. The amount of area lost was estimated by 'blacking-in' the missing areas on the computer image and then re-estimating the leaf area. Thus for each group of leaves, two areas were recorded: 1. actual area, and 2. projected area assuming that no insect damage had occurred. The difference between these two areas provides an estimate of leaf area loss. Differences in leaf area and leaf area loss between healthy and declining trees were tested by one-way analysis of variance (ANOVA).

3.5 Processing and sub-sampling of canopy invertebrates

The sheets from each tree were unfolded on tables and large invertebrates were removed by hand. To save time smaller invertebrates were not collected individually, but were gently swept off with soft brushes. Both small and large invertebrates were placed together in 70% alcohol for transport to Adelaide.

The very large number of invertebrates collected from most trees made it impractical to count and identify every individual. A sub-sampling strategy was devised to estimate the total number of individuals in each invertebrate group. The invertebrates collected from each tree were poured into a large petri dish (184mm diameter). A quick search removed large and/or unusual invertebrates, and the remainder were then dispersed as uniformly as possible across the dish. Nineteen potential sampling points were located in the petri dish by placing a diagram (Appendix 4), beneath the dish. For each tree, 8 of the 19 points were randomly chosen for sub-sampling., A circular quadrat of 10mm radius was placed at each chosen sample point and all invertebrates within the quadrat were removed for counting and identification. The area of the 8 sub-samples was equivalent to 9.5% of the total area of the petri dish.

Each of the eight sub-samples was processed separately. Invertebrates were identified to Order, with the exception of the Order Hemiptera which were further divided into sub-orders. Within each of the groups specimens were separated into "types", based on their physical appearance, and voucher collections were established. In some cases "types" can be equated to species, but in others it is almost certain that different "types" are the same species and simply represent different sexes or different stages of development. When the invertebrate work is completed it is anticipated that at least some of these vouchers will be sent to appropriate experts for complete identification. For each sub-sample, the number of "types" in each order was recorded, and the total number of individuals for the order was also recorded.

3.6 Tree canopy volume sampled for invertebrates

Although 2m x 2m sheets were laid under each tree that was to be sampled, the actual volume of canopy sampled varied considerably from tree to tree. There were several reasons for this:

- the trees varied in height;
- the base of the canopy varied in height above the ground;
- in several cases the canopy area was not sufficiently large to accommodate the 2m x 2m sheets; and
- the density of the foliage varied from tree to tree.

An adjusted canopy volume was calculated for each tree by using the equation:

$$V^* = s(h - b)(I)$$

where: V^* is the adjusted volume;
s was the area of sheet in m^2 (usually $4m^2$);
h was the height of the tree (in m);
b was the height of the base of the canopy above the ground (in m); and
I was the index of canopy density.

"I" was subjectively determined by examining each tree and placing it in one of five categories. The categories and their I values are shown in Table 1. Multiplying the canopy volume by I provides some allowance for the fact that some trees had far more leaves than others and, therefore, a much greater area to accommodate invertebrates. The estimated total number of invertebrates was then divided by V^* to give a number per m^3, and this standardised value was used in ANOVA's to compare different tree types.

Table 1. Categories of tree canopy density and associated values of "I".

Canopy Category	I
Very dense	1.0
Dense	0.8
Average	0.6
Sparse	0.4
Very sparse	0.2

4.0 Results

4.1 Preliminary Survey

Flooded gum decline was widespread, but the degree of severity was variable. For example, at Perry Lakes, which has an extensive stand of mature trees and some saplings emerging in the reed beds, nearly all trees were healthy. (Throughout the results and discussion the terms "healthy" and "declining" are used and are based on subjective assessment of canopy condition.) The exception was a group of trees on the south east side of the south east lake, where a number of trees were in obvious decline. In contrast, all trees at Neil McDougall Park were affected to some degree and none were assessed to be healthy. At most sites, trees adjacent to one another could be in quite different health.

There was one exception to this highly variable pattern. At Waterford there did seem to be a definite pattern to the decline. Starting with a strip of trees that had been defoliated (presumably in 1998) and had since produced regrowth, there was a relatively abrupt change, upstream, to a strip where nearly all trees were severely affected with many brown leaves and some defoliation. In this strip there was no regrowth. Further upstream there was another relatively abrupt change to healthy trees. These changes occurred over 200-300m. At no other time during this study was such a regular pattern observed.

During these visits, an obvious association between decline and the presence of lerps was noted. For example, healthy trees at Perry Lakes had almost no lerps on their leaves, but the group of declining trees at Perry Lakes, mentioned above, had obvious infestations of lerps. The sequence observed at Waterford was similar.

4.2 Survey of Swan River

4.2.1 <u>Tree decline:</u> Figure 1 shows the areas where flooded gum occurs along the river and indicates the decline category (see Appendix 1) for each 100m strip. Flooded gum became progressively more common upstream and in some areas formed almost continuous lines along the banks. Figure 1 shows that the degree of tree decline was quite variable with unaffected strips (Category 1) often being contiguous with severely affected strips (Category 3 or 4). At Guildford strips on the northern bank were classified as unaffected, but on the southern bank there were some severely affected strips.

Classification on the basis of 100m strips obscures finer-grained variability that was also present. It was unusual for all trees in a strip to be affected to the same degree, and often healthy trees were present in strips that were classified in Categories 3 and 4.

In summary, declining trees were found along the entire length of the Swan River that was surveyed. Considerable variability was noted both between and within survey strips. The widespread, but highly variable, distribution of declining trees made it impossible to discern any pattern in their distribution.

4.2.2 <u>Associations between tree decline and other factors:</u> Categories of tree decline were tested against tree mix, type of understorey/groundcover, land use in the area and land use in the area on the landward side of the trees. Possible associations were tested by use of contingency Chi-square.

Tree mix categories gave an indication of tree age and the mixture of trees of different ages. Cross-tabulation of tree mix and decline categories is given in Appendix 5, together with descriptions of the categories. Tree mix Categories 1 (all saplings) and 3 (young trees only) were not encountered. Category 7 (all mature trees) was the most common, and Category 4 (saplings, young and mature trees) was the next most common. After amalgamating categories (Appendix 5) to satisfy the requirements of the Chi-square test, the contingency Chi-square was significant [$\chi^2 = 10.42$, 3 degrees of freedom (df), $p < 0.02$]. In part this was due to an excess of Category 7 tree mix in the decline category 1 (all trees healthy) and a deficiency of Category 7 in decline category 3. This suggests that mature trees were less affected by decline, however an excess of Category 7 in decline categories 4 and 5 contradicts this suggestion. Separate survey data from the floodplain (Appendix 5) showed little sign of any association. However, data collected from the boat (Appendix 5), do suggest an excess of Category 7 in decline category 1.

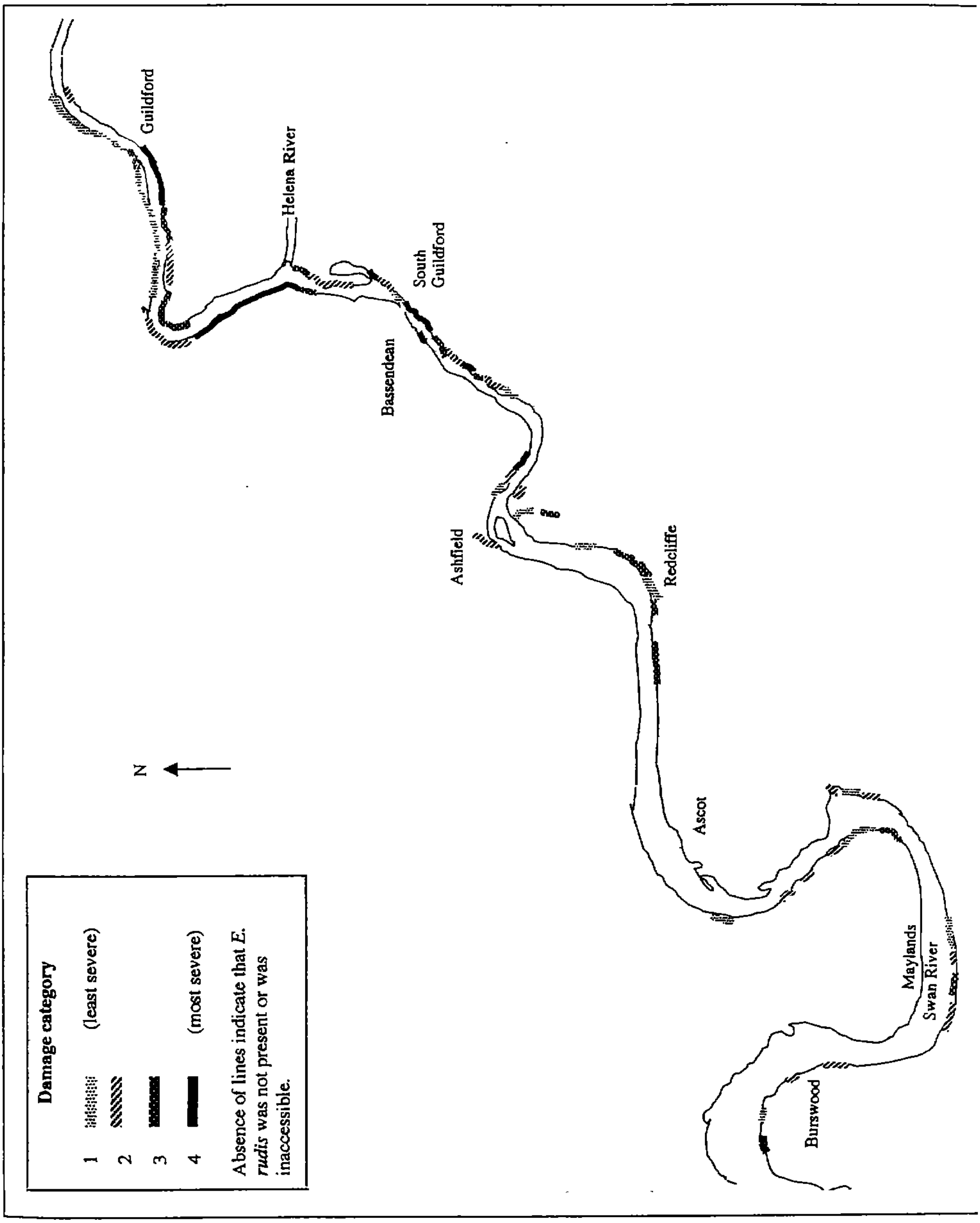

Figure 1. Map of the Swan River between the Perth CBD and Guildford, showing occurrence of flooded gum and the condition of the tree canopies in October 1999. (Note that flooded gum occurs along the north-western side of the river between Sandy Point Reserve-Ashfield and Point Reserve-Bassendean, but these trees occur on private property and could not be assessed.)

Cross-tabulation of tree decline and understorey/groundcover categories is given in Appendix 6, together with descriptions of the categories. Only Categories 2, 3 and 4 of understorey/groundcover were encountered. That is, all understoreys were modified at least by weed invasion, and usually were modified to the point of absence of any native species. After amalgamating categories, the contingency Chi-square was significant ($\chi^2 = 11.34$, 4 df, $p < 0.03$). This was largely due to an excess of decline category 1 (all healthy) and deficiency of other decline categories over understorey category 2 (native vegetation and weeds). This suggests that the condition of the understorey/groundcover may have an influence on tree decline. Data from the Helena floodplain and data collected by boat do not support this suggestion (Appendix 6).

Cross-tabulation of tree decline and land use categories is given in Appendix 7, together with descriptions of the categories. The most common land use was low-key recreation. Contingency Chi-square indicates lack of association ($\chi^2 = 2.73$, 6 df, $p > 0.8$) between the two types of categories. Data from the floodplain and the boat also support this view (Appendix 7).

Cross-tabulation of tree decline and backing land use categories is given in Appendix 8, together with descriptions of the categories. The most common land uses adjacent to the trees were, grasslands, parks or houses. The contingency Chi-square indicates a lack of association ($\chi^2 = 2.40$, 3 df, $p = 0.5$) between the two types of categories. Data from the floodplain and the boat also support this view (Appendix 8).

4.3 Comparisons of healthy and declining trees

Table 2 summarises the results of assessment of healthy and declining trees for different types of biological damage In most cases the results for healthy and declining trees are identical, or very nearly so, and no statistical analyses were done. Differences in presence of lerps, leaf necrosis and stem borer damage were tested statistically and only a significant difference in lerp presence between healthy and declining trees was found ($\chi^2 = 26.2$, 2df, $p < 0.001$). Lerps were more prevalent on declining trees, as indicated in Figure 2. The results suggest that damage due to the other biological agents did not contribute to tree decline.

4.4 Leaf area and leaf area loss for trees used to sample invertebrates

None of the differences in leaf area loss between healthy and declining trees were statistically significant at any site. Table 3 summarises leaf areas for the three sites, and leaf area loss, the most important measure, is illustrated in Figure 3. (Data for each tree and means are shown in Appendix 9.) The results suggest that loss of leaf area was not contributing to tree decline. It should also be noted that the leaves at Whiteman Park Site 1 were considerably larger than those at Site 2 and those at Guildford, however differences between sites were not tested statistically.

4.5 Lerp densities on trees used to sample invertebrates

Although average densities varied considerably between sites, the lerp density was always higher on declining trees than on healthy ones. Figure 4 shows that this difference was greatest at Site 2 (Whiteman Park). (The total number of lerps and lerp densities per sample are given in Appendix 9.) Differences between the two types of trees were tested statistically for each site by ANOVA of square root transformed data (Appendix 11). At all sites there was a significant difference between lerp densities on healthy and declining trees. There was also considerable variation between trees of the same type, and in a few cases individual trees, classified as healthy, had higher lerp densities than some trees, at the same site, classified as declining.

4.6 Necrosis on trees used to sample invertebrates

Generally, trees at Whiteman Park Site 1 were less affected than trees at Site 2 and at Guildford. However, the important comparisons are between healthy and declining trees at each site, and average category values (Table 4) suggest that declining trees are worse affected than healthy trees in Whiteman Park. The reverse is the case at Guildford. (The assessment of necrosis for each branchlet is given in Appendix 9.)

Table 2. Categories of biological damage in healthy and declining trees.

Tree Condition	Degree of Damage*		
	Presence of Lerps		
	1	2	3
Healthy	12	10	3
Declining	0	5	20
	Degree of Insect Chew		
	1	2	3
Healthy	18	7	0
Declining	18	7	0
	Leaf Miner Damage		
	1	2	3
Healthy	17	7	1
Declining	16	7	2
	Leaf Blister Damage		
	1	2	3
Healthy	20	5	0
Declining	20	5	0
	Leaf Necrosis		
	1	2	3
Healthy	15	9	1
Declining#	7	6	1
	Stem Gall Damage		
	1	2	3
Healthy	24	0	1
Declining	23	2	0
	Stem Borer Damage		
	1	2	3
Healthy	17	6	1
Declining	19	3	3

* Damage categories: 1 = minimal; 2 = some; 3 = considerable.

It was not possible to assess all declining trees because of excessive leaf discoloration.

Table 3. Comparisons of average leaf area, projected leaf area and leaf area loss for healthy and declining trees at each site.

Site	Tree Condition	Area (cm^2) Actual	Projected	Lost	% Area Lost
Whiteman Park Site 1	Healthy	89.8	95.6	5.8	6.1
	Declining	92.6	97.9	5.2	5.4
Whiteman Park Site 2	Healthy	52.3	56.7	4.4	7.8
	Declining	60.2	66.3	6.2	9.3
Guildford	Healthy	52.0	60.2	8.3	13.7
	Declining	51.8	58.1	6.3	10.9
Average for All Sites	Healthy	64.7	70.9	6.2	9.2
	Declining	68.2	74.1	5.9	8.5

Statistical analyses (Appendix 10) support the suggestions from Table 4. At Whiteman Park Site 1, there were significantly more healthy trees in Category 1 than declining trees, but at Guildford the reverse was true (χ^2 = 3.95 & 4.02, respectively, 1df, $0.04 < p < 0.05$) However, caution is needed because the number of samples is relatively small (five trees in each category at each site) and, in each case, the Chi-square was only slightly greater than the critical value There was no significant association at the other Whiteman Park site.

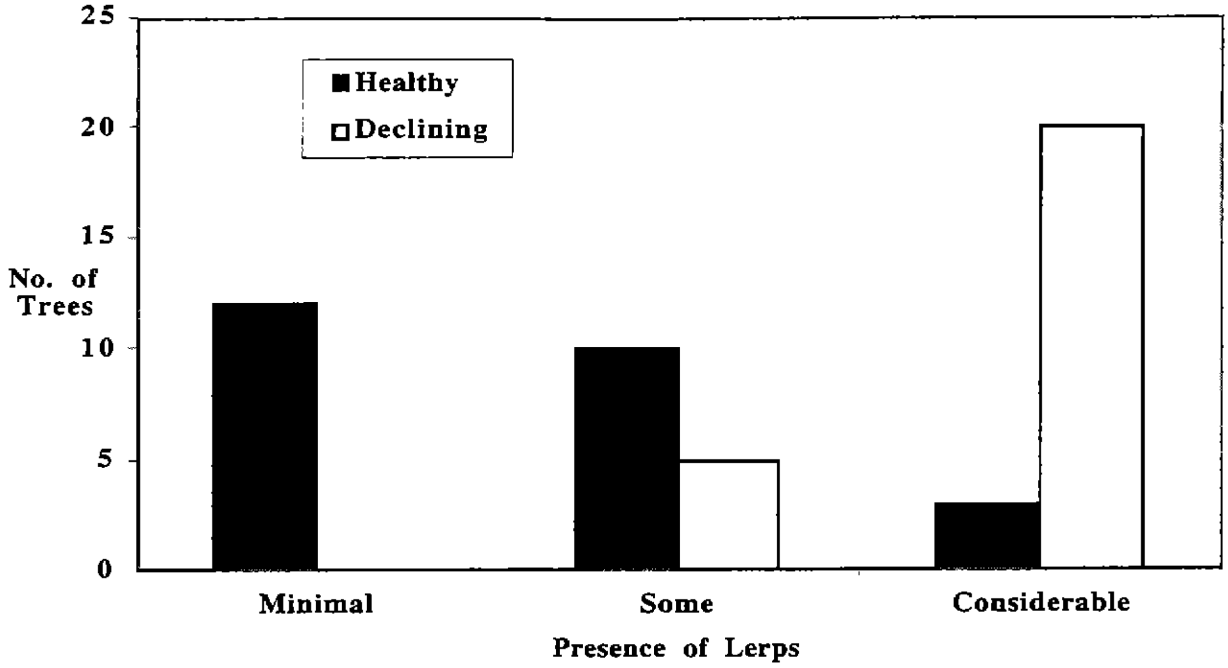

Figure 2. Comparison of the degree of lerp infestation on healthy and declining trees.

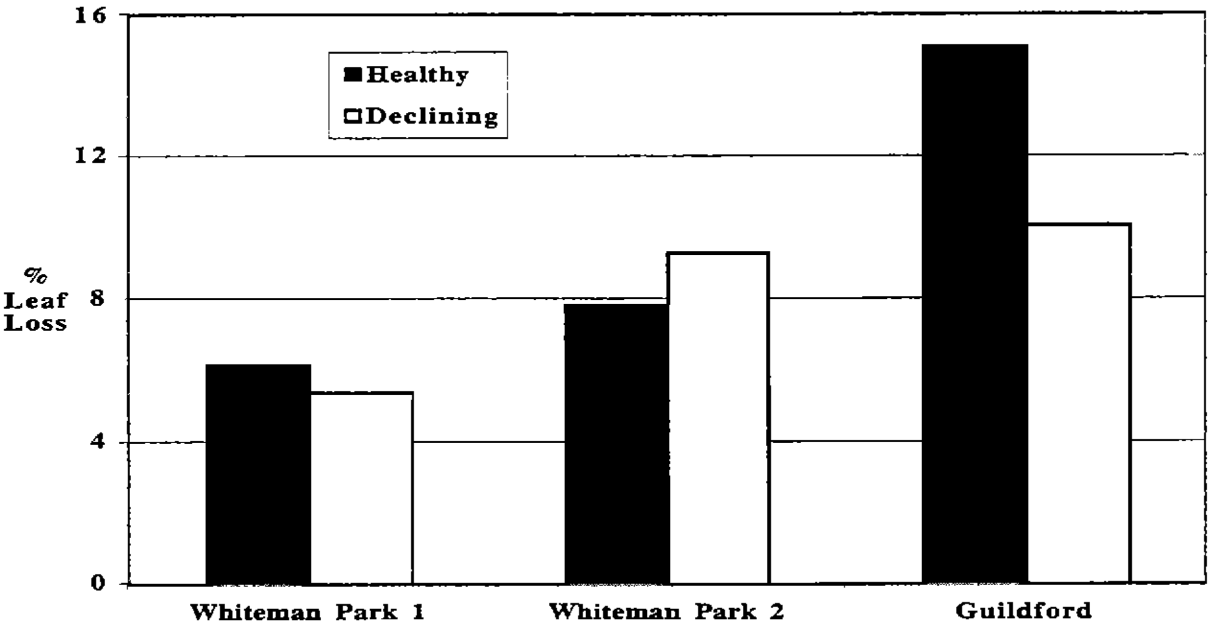

Figure 3. Comparison of percentage leaf area loss on healthy and declining trees at each site.

Table 4. Average category of necrosis for each tree type at each site. (Category 1 = 3%; 2 = 6%; and 3 = 12% of leaf area affected, respectively.)

Tree Type	Whiteman Park 1	Whiteman Park 2	Guildford
Healthy	1.4	2.6	2.9
Declining	2.0	3.2	2.4

4.7 Nutrient analysis of leaves from trees used to sample invertebrates

Only phosphorus, sulphur and calcium, differed significantly between healthy and declining trees. Nutrient concentrations for each tree are given in Appendix 11, and average values over all sites, for healthy and declining trees, are shown in Table 5, together with F values (and associated probability levels) from ANOVA's performed for each nutrient. Nitrogen levels have previously been found to be higher in declining trees (Landsberg 1990), but this was not the case here. In the case of some nutrients, values varied considerably between individual trees of the same type and from the same site. This type of variation made it difficult to show significant differences between tree types with relatively small sample sizes. Despite the apparently large difference in copper concentration between tree type (Table 5), a strong site by tree type interaction meant that the difference between trees was not significant.

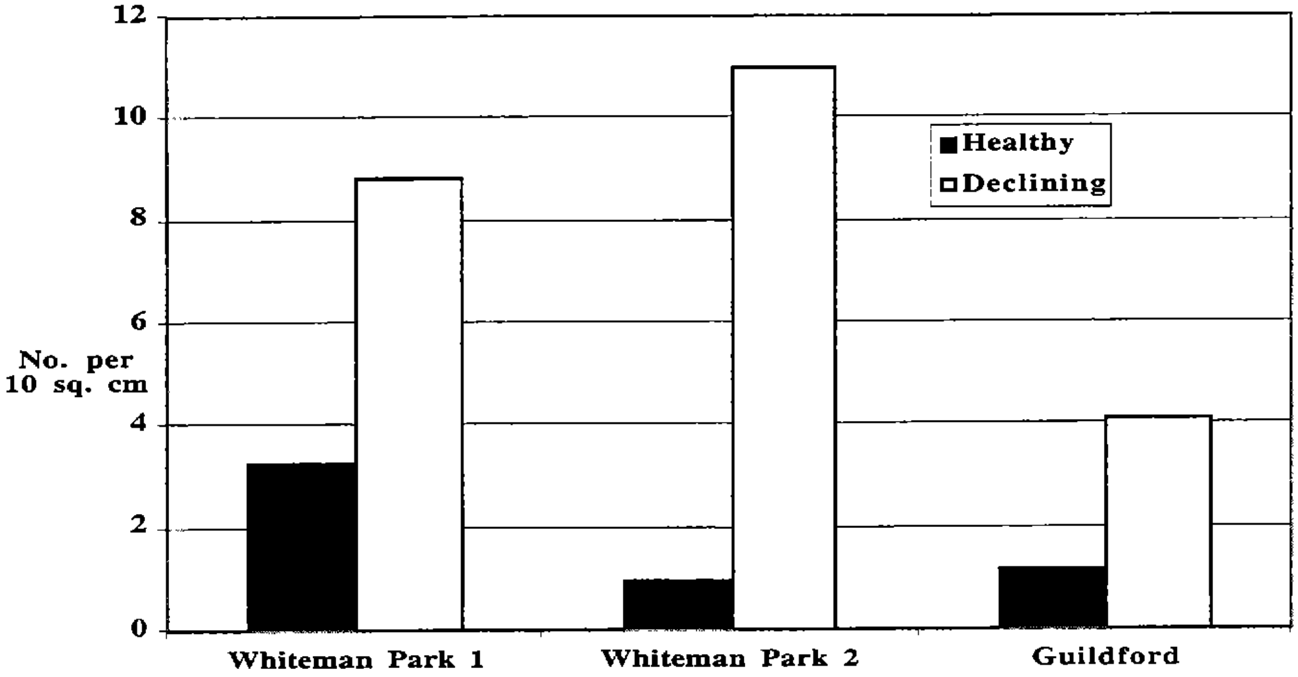

Figure 4. Comparison of lerp densities on healthy and declining trees at each site.

There were significant differences between sites for all nutrients except sulphur, copper and iron. These site differences are not the focus of this study and are not considered further, except to mention that manganese concentrations at Guildford were approximately ten times (1000%) higher than those at Whiteman Park. This magnitude of difference was not observed for any other nutrient, with the largest difference for any two sites being 59% (for calcium).

Table 5. Comparisons of healthy and declining trees for concentrations of twelve different nutrients averaged over all sites. (Concentrations are given in percentages for nitrogen, phosphorus, potassium, sulphur, sodium, calcium and magnesium. The concentrations of the remaining nutrients are given in parts per million.)

Nutrient	Mean Value for Tree Type		F Value[†]
	Healthy	Declining	
Nitrogen	1.82	1.82	0.00
Phosphorus	0.119	0.161	13.26**
Potassium	0.664	0.737	1.27
Sulphur	0.153	0.171	5.48*
Sodium	0.285	0.337	3.99
Calcium	0.538	0.670	7.37*
Magnesium	0.187	0.214	3.04
Copper	6.02	4.82	0.45
Zinc	27.51	24.89	0.78
Manganese	413.9	404.5	0.01
Iron	55.3	63.7	1.79
Boron	46.71	50.49	1.05

† - derived from ANOVA's of raw data;
* F significant at the 5% level;
** F significant at the 1% level.

4.8 Estimated number of canopy invertebrates

These results are only presented for Whiteman Park. As indicated earlier, Guildford samples have not yet been processed. The estimated total number of invertebrates in each group for each tree are provided in Appendix 12. The estimated total number of invertebrates, from all groups, on each tree are given in Table 6. The average numbers for healthy and declining trees were 10,525 and 7,882, respectively.

Table 6. Comparisons of tree types for estimated total number of invertebrates and total number of invertebrates excluding adult psyllids. These comparisons are also given on a per m^3 basis to allow for different canopy volumes.

Tree Type	Tree No.	Estimated Total No. Invertebrates	Estimated Total No. Invertebrates excl. adult psyllids	Estimated Total No. Invertebrates per cu.m.	Est. Total No. Invertebrates excl. adult psyllids per cu.m.
Healthy	1	17522	5227	996	297
	2	19544	6929	1222	433
	3	21418	5697	1635	435
	4	14879	5297	2067	736
	5	8015	3340	786	328
	6	5192	4486	1038	897
	7	7350	5844	1114	886
	8	7401	4316	925	540
	9	3065	1991	281	183
	10	865	728	112	95
	Total	**105251**	**43855**	**10176**	**4830**
	Average	**10525.1**	**4385.5**	**1017.6**	**482.7**
Declining	11	13131	4149	1824	576
	12	2812	1327	625	295
	13	5013	1338	748	200
	14	6972	2139	968	297
	15	25754	9148	1922	683
	16	8393	7593	2798	2531
	17	8236	4993	1396	846
	18	4012	3170	557	440
	19	2898	2445	644	543
	20	1602	1202	458	343
	Total	**78823**	**37504**	**11940**	**6754**
	Average	**7882.3**	**3750.4**	**1194.0**	**675.4**

When Site 1 was sampled (Trees 1-5 and 11-15), conditions were warm, humid and overcast. This appeared to create ideal conditions for emergence and flight of adult psyllids. Psyllids were abundant in the air, on foliage and on workers. When Site 2 (Trees 6-10 and 16-20) was sampled a few days later, conditions were warm, sunny and much less humid and adult psyllids were much less obvious. These observations were confirmed by our counts and estimations of psyllid numbers. Healthy trees at Site 1 had, on average, 895 adult psyllids/m^3 compared to 174/m^3 on healthy trees at Site 2. Because of the dramatic change in the presence of adult psyllids, invertebrate comparisons are also given in Table 6 after adult psyllid numbers were excluded. The average numbers for healthy and declining trees, after exclusion of adult psyllids, were 4,386 and 3,750, respectively.

Comparisons with or without adult psyllid numbers suggest that there were more invertebrates on healthy trees. However, when adjustments are made for canopy volume sampled and the density of the canopy (see methods), the number of invertebrates is greater on declining trees, especially when adult psyllid numbers are excluded. There were 483 invertebrates/m^3 and 676 invertebrates/m^3 on healthy and declining trees, respectively, excluding adult psyllids. However, this was not uniform across the two sites. Table 7 shows that, on average, there were slightly more invertebrates on healthy trees than declining trees at Site 1, but that there were many more invertebrates on declining than healthy trees at Site 2. Table 7 also shows that most invertebrate groups had similar average numbers on healthy and declining trees at each site.

Table 7. Average number of individuals, for each invertebrate group, captured per cubic metre of canopy on different tree types at two sites at Whiteman Park.

Class, etc.	Site 1		Site 2	
	Healthy Trees	**Declining Trees**	**Healthy Trees**	**Declining Trees**
Acarina (mites)	17.7	6.5	20.1	85.9
Araneae (spiders)	9.7	5.3	16.0	29.1
Coleoptera (beetles) - adults	23.2	25.6	34.3	38.6
- larvae	5.9	4.6	4.5	12.8
Collembola	13.3	1.6	2.0	9.9
Diptera (flies)	55.3	65.1	61.3	74.5
Heteroptera (bugs) - adults	2.5	4.1	4.7	10.1
- nymphs	1.4	1.3	5.4	12.5
Auchenorrhyncha - adults	36.1	20.9	31.4	47.5
(leaf hoppers) - nymphs	29.9	37.9	108.4	137.4
Sternorrhyncha - adults	895.3	807.3	174.3	229.6
(psyllids) -nymphs	20.9	44.1	17.4	65.2
Vespoidea (wasps)	117.1	113.5	36.9	64.9
Thysanoptera (thrips)	98.0	63.3	150.3	320.1
Others	2.3	6.4	11.7	16.5
Unidentified	5.7	1.3	5.8	5.4
Too damaged to ID	6.7	8.7	9.8	10.4
Average Total No.of Inds.	**1340.9**	**1217.4**	**694.1**	**1170.5**
Average Total No.of Inds. (excl. adult psyllids)	**445.6**	**410.1**	**519.9**	**940.9**

A two-way (sites and tree type) analysis of variance was performed on the standardised data (invertebrates/m^3) for total invertebrates, for total invertebrates excluding adult psyllids and for each major invertebrate group. Despite the relatively large difference between the overall averages for healthy and declining trees (noted above), there was no significant difference between the tree types in their number of invertebrates, or their number of invertebrates when adult psyllids were excluded from the analysis (F = 0.343 and 0.715, respectively). Nor was there a significant difference between sites for total number of invertebrates, despite the large numbers of adult psyllids encountered at Site 1. This highlights the considerable variability between trees of the same type, at the same site, which can be seen by inspection of the last two columns in Table 6. Lack of uniformity in results across the two sites also contributes to the failure to show significant differences.

Similarly, ANOVA's for each major group of invertebrates (adult beetles, flies, adult hoppers, hopper nymphs, adult psyllids, psyllid nymphs, wasps, thrips, mites and spiders) generally failed to show any significant differences in number for tree type or sites. The only exception for tree type, were the numbers of psyllid nymphs. On average, healthy trees had 19.1 nymphs/m^3 of canopy and declining trees had 54.6 nymphs/m^3 , a difference which was significant ($F = 4.688$; df 1,16; $p<0.05$). Significant differences between site averages were found for hopper nymphs, adult psyllids, wasps and spiders. There were more adult psyllids and wasps at Site 1, but more hopper nymphs and spiders at Site 2.

The similarities in invertebrate groups, between different tree types, are also illustrated in Figure 5, where proportions are compared. Wasps made up a greater proportion of invertebrates at Site 1 than Site 2, but thrips and, to a lesser extent, leaf hoppers, were more important at Site 2 than Site 1.

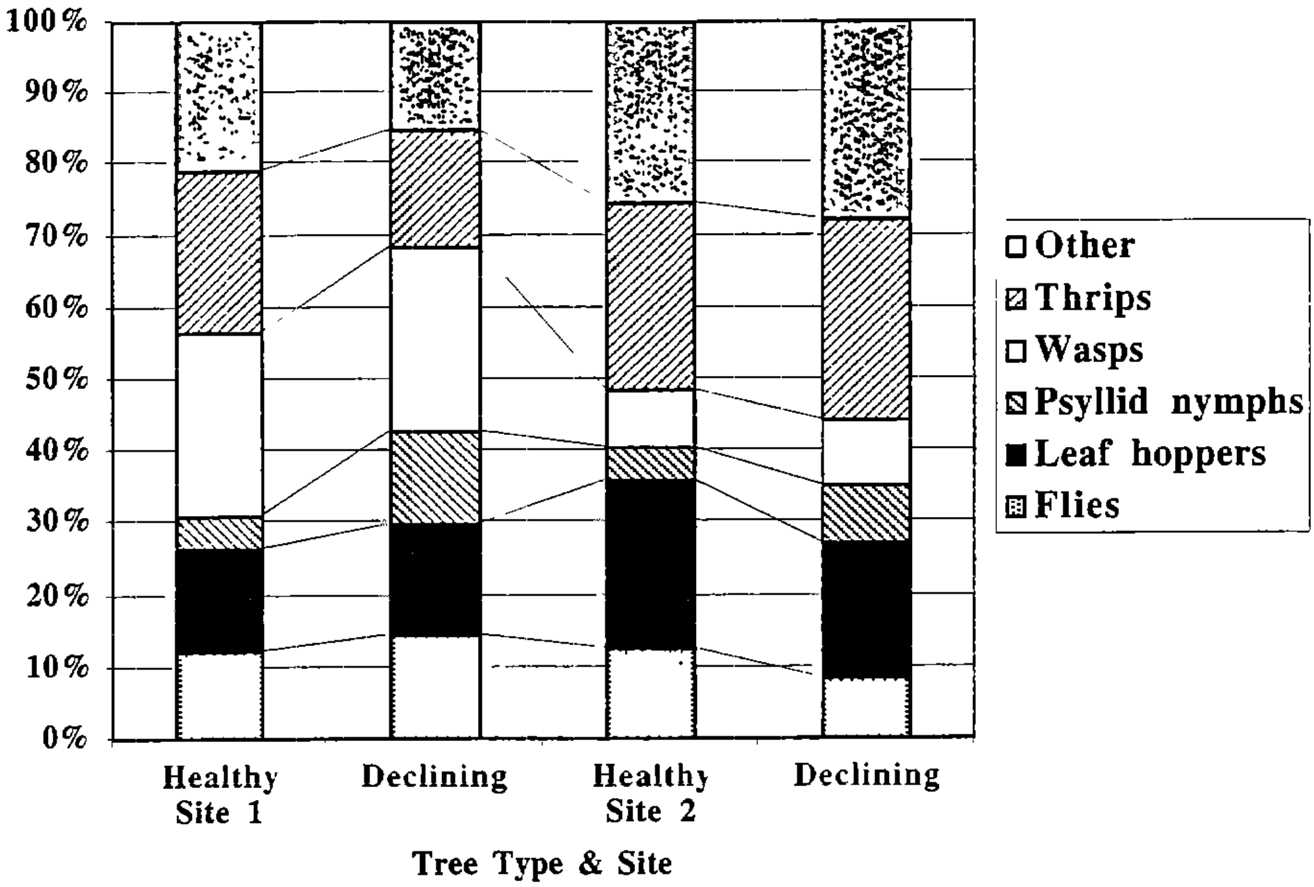

Figure 5. Proportions of the major invertebrate groups found on healthy and declining trees at two sites in Whteman Park.

5.0 Discussion

The preliminary survey showed that dieback in flooded gum was widespread in the Perth urban area in the spring of 1999. Although some trees were observed to be almost completely defoliated, no trees that were unequivocally dead were observed. We concluded that the dieback was in the early stages of progression and that most, if not all, trees were probably experiencing their first round of leaf death and defoliation. However, we also concluded that this episode of dieback in flooded gum began prior to 1999, because some trees were observed, e.g. at Waterford and Whiteman Park, to have produced epicormic growth in response to defoliation in 1998, or earlier.

The observations of the preliminary survey were confirmed by the more comprehensive survey of the Swan River from the Perth CBD to Guildford. Decline in flooded gum was:

- widespread;
- very variable and without any obvious pattern; and
- obviously associated with high densities of psyllid lerps on the leaves.

The Swan River survey provided the opportunity to investigate possible associations between the severity of decline and various site characteristics. There was a statistically significant, but rather inconclusive (from a biological point of view), association between the mix of tree types and the index of decline. The mixture type that only included mature trees was disproportionately represented in the "healthy" index when compared to other mixtures. In discussing psyllid outbreaks, Morgan (1984) has indicated that a mixture of different tree age-classes favours outbreaks. Therefore, in areas that only contain mature trees, psyllid infestations may not establish as easily and leaf damage and defoliation may be less common. Morgan's observations could explain the association between the "mature tree" mix and the "healthy" index However, in contrast to Morgan's observations, we also observed an excess of the "mature tree" mix in decline categories 4 and 5, the most severely affected categories. The importance of a mixture of tree age-classes appears to vary with psyllid species. The psyllid *Cardiaspina jerramungai* can cause severe defoliation on flat-topped yate (*Eucalyptus occidentalis*) in Western Australia; the most severe outbreaks, with repeated defoliation, occur in stands containing only mature trees (pers. comm. Janet Farr, December, 2000). In this case, a mixture of leaf age-classes is important to sustain the psyllid outbreak (pers. comm. Janet Farr, December, 2000). Farr's findings about tree age-class contradict Morgan's (1984) results and highlight the importance of understanding the biology of the psyllid species involved. Such understanding is lacking for *Creiis periculosa*, the psyllid in high density on flooded gum.

There was also a significant association between decline index and the category of understorey/groundcover. There was an excess of "healthy" trees observed to be growing over "native vegetation and weeds" as opposed to "mainly weeds" or "mown grass". It is likely that the more natural understorey (still containing a significant proportion of native plants) provides more food sources and greater shelter for native invertebrates which are natural controllers, by predation and parasitism, of foliage feeding insects. Morgan (1948) has stressed the importance of lack of natural controls as one of the causal factors in psyllid outbreaks and it may be that there is such a lack in our survey areas with weedy or mown grass understoreys. Comparison of flat-topped yate stands with, and without, native understorey also provide supporting evidence. Canopy decline and defoliation were less severe on trees growing in National Parks compared to those in adjoining farmland, even though initial psyllid densities were high in each type of location. These high densities were not maintained on trees in National Parks (pers. comm. Janet Farr, December, 2000).

We also examined the possibilities that use made of the areas, and/or the adjoining land uses, may influence the degree of tree decline. With only one exception, there was either little obvious use, low key recreational use or more intensive recreational use (e.g. a park). We found no association between type of land use and categories of tree decline, and there was a similar lack of association between categories of adjoining land use and tree decline. (The most common adjoining uses were 'grassland', 'park' and 'housing'.)

5.1 Comparisons of healthy and declining trees

During the preliminary stages of this study, a number of people provided suggestions about the possible cause of the flooded gum decline. Most commonly, insects were implicated. We commonly observed leaf damage and attributed it to chewing insects, leaf miners, insects that cause galls and bacterial and fungal diseases. Similarly, damage caused by stem borers and stem galling insects was observed. Generally, damage of a specific type to any individual tree was not great and there were only a few instances where the degree of damage was categorised as "considerable". The exception was lerp infestation, with almost half the trees being rated to have "considerable" lerp presence.

In attempting to verify the possible importance of the various types of damage in tree decline, the absolute amount of damage is less important than comparisons of healthy and declining trees. With only one exception, statistical analysis of the results showed no association between the degree of damage and tree health. Again the exception was lerp infestation - most of the declining trees were categorised to have "considerable" lerp presence, whereas most healthy trees had "minimal" or "some" lerp presence.

Our conclusion from these assessments of healthy and declining trees is that there was a definite association of psyllid infestation with declining tree health, but that no such association existed for the other types of biological damaged surveyed. However, this conclusion could be questioned because it is based on subjective assessment and categorisation of entire trees and, as such, is potentially subject to observer error and/or bias. In an effort to counter this type of criticism, leaves of a subset (15 trees of each type from three sites) of the assessed trees were examined in more detail.

Estimated leaf area lost to various types of chewing/mining insects was shown to be no different for healthy versus declining trees, thus verifying our subjective assessments. Assessment of leaf necrosis was less unequivocal, with analysis from one site suggesting that declining trees were more affected, a second site suggesting they were less affected, while the third site suggested no difference between healthy and declining trees. These contradictory results, together with small sample sizes at each site and Chi-square values that were only slightly larger than the critical values, make a conclusion impossible and suggest that further research is warranted.

By contrast, there was no contradiction from the analyses of lerp densities. At all sites, there were significantly higher lerp densities on leaves from declining trees than those from healthy trees. This confirms our subjective assessment discussed above, and also supports Yeoman's (1999) reporting of a much greater density of the psyllid *Creiis periculosa* on less healthy flooded gums. However, it should be noted that considerable tree to tree variation existed and some trees classified as "healthy" actually had high lerp densities. There are several possible reasons for this including

- incorrect subjective assessment of the tree as "healthy";
- inadequate sampling of the leaves from each tree such that the sample was not reflective of the average condition of leaves on the tree; and
- the possibility that a large, synchronised infestation by psyllids had occurred too recently to produce the observable leaf damage that would have led to the classification of the tree as "declining".

5.2 Nutrient analysis

A key component of White's (1986) theory on the cause of dieback (see Section 1.2) is an increase in available nitrogen produced by trees that are under stress. This increase leads to greater survival of herbivorous insects and therefore rapid increases in population sizes. Landsberg (1990) provided support for White's theory by showing that declining trees of *Eucalyptus blakelyi* in eastern Australia had higher leaf nitrogen than healthy trees. Our analysis of leaves from declining and healthy trees of flooded gum did not support this theory. Mean nitrogen content in the two types of trees was identical, although the level of phosphorus was significantly higher in leaves from declining trees than those from healthy trees. Yeomans (1999) also found no significant difference in nitrogen level in flooded gum, but unlike us, she also found no significant difference for phosphorus. In our study, sulphur and calcium levels were also significantly higher in leaves from declining trees.

Nitrogen is a critical nutrient for growth and reproduction of all organisms and is often a limiting factor for individuals and populations. These facts have obviously influenced the development of White's (1986) theory on the cause of dieback. However, we should also acknowledge that phosphorus is another important nutrient which, in Australia in particular, is often at critically low concentrations. Therefore, it is possible that the significantly elevated phosphorus levels in declining trees are a contributing factor to the marked increase in psyllid populations. Of necessity, this is a tentative suggestion. Our small sample sizes, and the fact that Yeomans (1999) failed to find any difference in foliar phosphorus concentrations, point to the need for more investigation of the possible relationship. Yeomans (1999) has also stressed the importance of an appropriate sampling strategy when measuring foliar nutrients.

Calcium and sulphur are also important nutrients, but usually are more readily available than nitrogen and phosphorus, and are therefore likely to be less critical for organisms. However, their elevated concentrations in declining trees, compared to healthy ones, may be related to high psyllid numbers and may warrant further investigation.

5.3 Canopy invertebrates

The most notable aspect of the canopy invertebrate results was the very high abundance of invertebrates. In contrast to the numbers of invertebrates found in canopies of trees in native Western Australian forest (Recher *et al.* 1996), abundances on the flooded gums that we sampled were more similar to those that might be expected from Australian subtropical rainforests (Majer 1990).

Also notable was the extreme variability in invertebrate numbers between trees of the same type and at the same site. For example, for healthy trees at Site 2 there was more than an 8-fold difference between the smallest and largest number of invertebrates collected from individual trees. Even after corrections were made for differences in canopy volume and density, large differences persisted. For example, for healthy trees at Site 2 the difference between smallest and largest actually increased to almost 10-fold. Such large variability, combined with small sample sizes and lack of uniformity across sites, make it very difficult to detect any real differences in canopy invertebrates that may be present. The design for any future sampling must address these issues.

It is not surprising, therefore, that a significant difference between healthy and declining trees was found for only one invertebrate group - psyllid nymphs were found in significantly higher numbers on declining trees than healthy ones. This is a particularly noteworthy result in light of the reported higher lerp densities on declining trees (see above). We assumed that the starchy lerps would protect their associated psyllid nymphs from the knockdown insecticide and that few, if any, nymphs of the species *Creiis periculosa* would be collected. However, nymphs of free-living psyllid species, that do not produce a lerp, would be killed by the insecticide and collected. We are therefore faced with two possibilities:

- the lerps did not provide as much protection as we had assumed and relatively large numbers of *Creiis periculosa* nymphs were collected; or
- nymphs of free-living species of psyllids were also present in significantly greater numbers on declining trees than healthy trees.

Currently, our processing of the psyllids does not allow us to distinguish between these two possibilities.

Our main reason for sampling canopy invertebrates was to examine, in much greater detail, possible associations between invertebrates and dieback. For the various invertebrate groups we have examined, we have generally found greater differences induced by change of site rather than those induced by changes in tree health. Also there is a lack of consistency in results for the two sites; for example, mites were more common on healthy trees than declining trees at Site 1, but the reverse was true at Site 2. This type of reversal across the sites was not uncommon. Another possible contributor to variability in the results is our attempted correction for tree canopy size and density. The former, we feel, was determined with reasonable accuracy, but the subjective categorisation of canopy density into five classes may lack sufficient precision to provide an accurate estimation of canopy volume. It is possible that adoption of a quantitative approach to measuring canopy density might reduce some of the variability in results.

If there are any differences in canopy invertebrates between declining and healthy trees, they may only be detected by a change in sampling strategy. It may be more effective to sample a considerably smaller canopy volume on each tree, and to devote more time to accurately determining the sampled canopy volume. A larger number of trees should be sampled and, possibly, across more sites. Given the time invested in this sampling exercise, the prospect of undertaking a larger sampling exercise is daunting.

5.4 Possible causes of decline and the future for flooded gum

We expect that most, if not all, trees observed to be in decline in 1999 will have produced epicormic growth by the time of writing of this report (spring 2000). The critical question is whether this will lead to permanent recovery, or whether there will be another cycle of defoliation and epicormic growth, thus establishing the typical pattern of dieback observed in other eucalypt species in other parts of the country. The answer to this question requires a knowledge of the causal factor(s), and we do not have this knowledge. However, the present study has indicated that some possible causes are more likely than others.

The widespread distribution of declining trees tends to eliminate any cause that is site-specific (localised), for example jettisoning of aviation fuel near the airport, or fluoride emissions from brickworks around Guildford (both suggested as possibilities). A more widespread phenomenon is the lowering of watertables, which is likely to adversely affect a species whose normal habitat is very close to water. Certainly in some locations, e g, Whiteman Park, falling watertables are a well-documented phenomenon, and decline is thought to be occurring commonly across Perth where many households have their own bores. However, the variable locations in which declining trees were found does not support a causal role for falling watertables. For example, declining trees were observed to be growing almost in water along the Canning River and at Neil McDougall Park; it seems highly unlikely that these and other similar trees were suffering from water deficiency.

For similar reasons it is unlikely that below average rainfalls in Perth, prior to this study, have caused the tree decline. Although altered rainfall patterns has been implicated in eucalypt decline in Australia (see, for example, White 1986), the observed proximity of some declining flooded gum trees to permanent water suggests that alterations in water availability to the roots have not occurred. However, if altered rainfall patterns are a causal factor, cycles of decline may re-occur in association with the predicted effect of global warming on rainfall patterns.

Other possible causal factors are raised watertables and/or increased salinity. Permanently raised watertables will deprive roots of essential oxygen and lead to tree death. River red gum, which is closely related to flooded gum, has been killed in this way in eastern Australia. However, it seems doubtful that this is a problem in Perth. As indicated above, the general perception appears to be that quite the reverse is occurring with falling watertables. There also seems to be no reason for the average levels of rivers, such as the Swan and Canning, to be rising and permanently flooding tree roots. During our survey we encountered only one small site where a permanently raised watertable might be implicated in flooded gum decline. This was on the edge of a golf course in Churchlands, where a small drainage channel appeared to have been blocked.

Increases in salinity in wetlands and waterways appear to associated with extensive decline of flooded gum in rural Western Australia, but there is no evidence that this is the case in Perth. We assume that decline caused by salinity would extend progressively as the influence of salt spread to different locations. By contrast, the onset of decline in Perth has been rapid (2-3 years at the most) and widespread. Also, observation of salt affected flooded gum in rural Western Australia suggests that all trees are affected, whereas the patchiness of the decline in Perth was notable, and does not match the rural pattern. These observations lead us to believe that increasing salinity is unlikely to be a causal factor in Perth. However, we have no data on long term salinity levels and could not attempt to measure any within the scope of this study. It is quite likely that salinity is increasing, and this is a potential cause that requires further investigation.

Another possible causal factor is nutrient enrichment of waterbodies. Runoff from agricultural land, stormwater runoff, industrial discharge and discharge/seepage from domestic sewerage systems are all likely to contribute nutrients, particularly nitrogen and phosphorus, to wetlands, waterways and groundwater. This has become a common phenomenon throughout Australia and it seems reasonable to assume that Perth is no exception. In fact, high concentrations of nitrogen have been measured in the Helena River (pers. comm. Barbara Dundas, Helena Catchment Group). If this is common to waterbodies in Perth, it is possible that their associated flooded gums also have elevated nutrient levels, which will favour outbreaks of herbivorous insects. However, it seems more likely that decline in flooded gum caused by increasing nutrient levels would follow the pattern proposed for increasing salinity (above) and not cause widespread, but patchy, decline over a short period of time. Of course, both in the case of salinity and nutrient levels, it is possible that some other environmental factor(s) interact(s) with them and triggers a synergistic effect on the flooded gums at certain critical times. We conclude that the possible role of raised nutrient levels in tree decline should be investigated.

Finally, we must consider the role of biological agents. With the exception of psyllids, our study has found no evidence to support a role for a number of insect species, or for diseases that cause leaf necrosis. We have found a very clear association between psyllid infestation and tree decline. Are the psyllids the primary causal factor, or does their infestation merely indicate that the trees are already under stress from other causes, as White 1986 proposes?

If psyllids are the prime cause, we should expect decline to spread in some type of regular pattern from an initial point with a large psyllid population. This pattern of spread could still be patchy because there is evidence (e.g. Morgan 1984; White 1993) that psyllids are quite particular about the types of trees they feed and reproduce on. The age of leaves and the reproductive state of the tree (flowering or fruiting) can both influence psyllids in their search for suitable feeding sites. Since no systematic observations had been made in Perth prior to this study, we cannot comment on the pattern of spread – this is something that needs to be closely monitored from now on. We observed only one location where a regular pattern was discernible - at Waterford on the Canning River (see results). The observed pattern was very suggestive of an advancing front of psyllids.

5.5 What can be done about flooded gum decline in the long term?

Apart from the obvious need for further investigations to identify the primary cause(s) of decline, there is little that can be done. The size and number of trees involved, and their widespread distribution throughout Perth preclude any attempt to control the psyllids. Even if control could be achieved, it is obvious from the preceding discussion that this may only be treating a symptom and not the primary causal factor.

Since psyllids are an important contributing factor, there are some long-term strategies that could be implemented to reduce the impact of psyllids. These include:

- If trees can be located that are resistant to decline, seeds for plantings should be harvested from resistant trees in preference to those of susceptible trees.
- Apart from this limitation, seeds should come from a variety of sources to maintain genetic variability.
- Single-species plantings (monocultures) should be avoided.
- Re-establish native shrubs, herbs and grasses in the understorey of established flooded gum stands and in plantings. This is not only sensible from a conservation perspective, but also will maximise the opportunity to establish viable populations of psyllid predators and parasites.

5.6 What can be done about flooded gum decline in the short term?

For individual trees, or small groups, more direct and short-term action can be implemented by use of systemic insecticides. This will be expensive, and will only be an effective strategy if the psyllid infestation is at an early stage of development on the tree in question. If many leaves are already discoloured, any treatment would probably be too late to prevent extensive defoliation. However, after defoliation and when epicormic growth first appears, treatment may be effective in preventing re-infestation. It should be emphasised that this type of treatment has not been evaluated and experimentation will be necessary. It may also be necessary to make repeated insecticide applications because a tree that is "healthy" is likely to become a target for egg laying as suitable foliage becomes depleted on other, untreated, trees in the area. Monitoring of the tree(s) for establishment of small lerps will be essential.

Experiments with eucalypts in Tasmania (*pers. comm.* Dick Bashford, Forestry Tasmania) have applied liquid thiometon (Ekatin) or granular disulfoton (Disyston 50) to the ground for root uptake. Both of these insecticides provided some protection from insect herbivores. However, direct injection of liquid preparations into the trunks "gave much better results". Apart from the poorer outcome from ground application, there is much greater danger to non-target species, including pets, from ground application. It should be emphasised that these experiments have only been done on young trees, which were small (3-6m tall) compared to the size of mature trees in the Perth area. It is likely that high dosage rates and multiple injections, at various positions around the trunk, will be needed in order to control herbivores in large, mature trees.

Simple application of fertiliser to increase tree vigour has been shown to be quite effective, at least in the case of some herbivores. Since high foliar nitrogen in stressed trees has been suggested as a cause of psyllid outbreaks, this is a strategy that may not be appropriate for flooded gum dieback. Only experimentation can determine this.

6.0 Suggestions for Further Study

We recommend investigation of the following

- the change in distribution of tree decline over time,
- the progression and stages of decline on selected trees at various locations;
- the possible role of increasing salinity in waterbodies;
- the possible role of increasing nutrient concentrations (particularly nitrogen and phosphorus) in waterbodies;
- identification of other possible causal factors in flooded gum decline;
- the association of decline with landuse patterns;
- the relationship between causal factors and geographical location;
- genetic resistance to psyllid infestation in flooded gum;
- the best methods of treating individual trees that are in decline;
- identification of natural predators and parasites of the psyllid *Creiis periculosa*;
- best methods of encouraging larger populations of these predators and parasites;
- verification of higher foliar phosphorus, calcium and sulphur concentrations in declining trees and, if indeed concentrations are higher;
- the significance of the higher concentrations; and

- more extensive sampling of canopy invertebrates (perhaps with modification of some of the methods used in this study) to identify if there are other invertebrates contributing to decline.

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Appendix 1. Sample of data sheet used for area assessments.

Area No.	Description/Identification of Area	Transect	Decline Index	Tree Mix	Veg'n Depth	U-storey	Area Size	Use of Area	Backing Land Use	Comments

Appendix 1 (cont.)

- **decline index**:
  1 - all trees healthy
  2 - some brown or purple leaves visible
  3 - many brown or purple leaves & some branchlets defoliated
  4 - nearly all/all leaves brown &/or major defoliation
  5 - old defoliation with regrowth occurring

- **tree mix:**
  1 - all saplings
  2 - saplings & young trees
  3 - young trees only
  4 - saplings, young & mature trees
  5 - saplings & mature trees
  6 - young & mature trees
  7 - all mature trees

- **vegetation depth**
  indicate depth away from creek or wetland
  if walking transects, they should be no more than 40 metres wide

- **understorey/ groundcover:**
  1 - native vegetation
  2 - native vegetation & weeds
  3 - mainly weeds
  4 - mown grass
  5 - other (specify in comments

- **area size**
  indicate length & breadth of transect
- **use of area:**
  1 - little obvious use
  2 - low key recreation
  3 - intensive recreation/park
  4 - grazing
  5 - other (specify in comments)

- **backing land use:**
  1 - native vegetation
  2 - grassland
  3 - park
  4 - grazing
  5 - farming/horticulture
  6 - housing
  7 - roadway
  8 - industrial
  9 - other (specify in comments)

Appendix 2. Sample of data sheet used for assessment of knockdown trees.

General description of location______________________________ Date____________

____

General description of tree condition______________________________

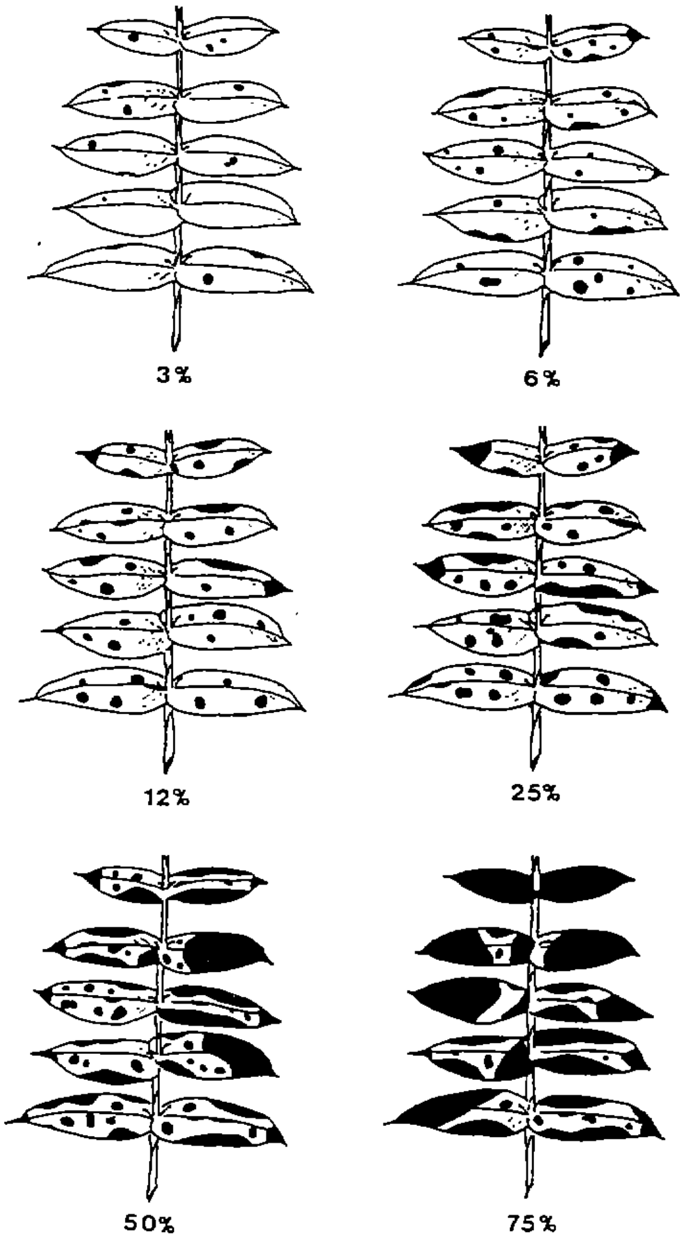
____

Tree Type	Decline Index	Insect Presence &/or Damage							Dist-ance to H_2O	Canopy Characteristics				
		Lerps	Insect Chew	Leaf Miner	Leaf Blister	Other Necrosis	Stem Galls	Stem Borer		Ht.to top (A)	Ht. to base (B)	(A) minus (B)	Rel. dens-ity	Rel. vol-ume

Appendix 2 (cont.)

- **tree type:**
    - 1 - sapling
    - 2 - young tree
- **decline index:**
    - 1 - healthy
    - 2 - some brown or purple leaves visible
    - 3 - many brown or purple leaves & some branchlets defoliated
    - 4 - nearly all/all leaves brown
- **insect presence &/or damage:** (Columns 3 - 9)
    - 1 - minimal
    - 2 - some
    - 3 - considerable
- **distance to open water** (m.):
    - 1 - <5
    - 2 - 5-10
    - 3 - 10-30
    - 4 - >30
- **relative density of canopy:**
    - 1 - very dense
    - 2 - dense
    - 3 - average
    - 4 - sparse
    - 5 - very sparse

Appendix 3. Diagrams from Carnegie *et al.* (1994) which were used to classify the degree of necrosis on leaves taken from trees that were used to sample canopy invertebrates at Whiteman Park and Guildford.



3%

6%

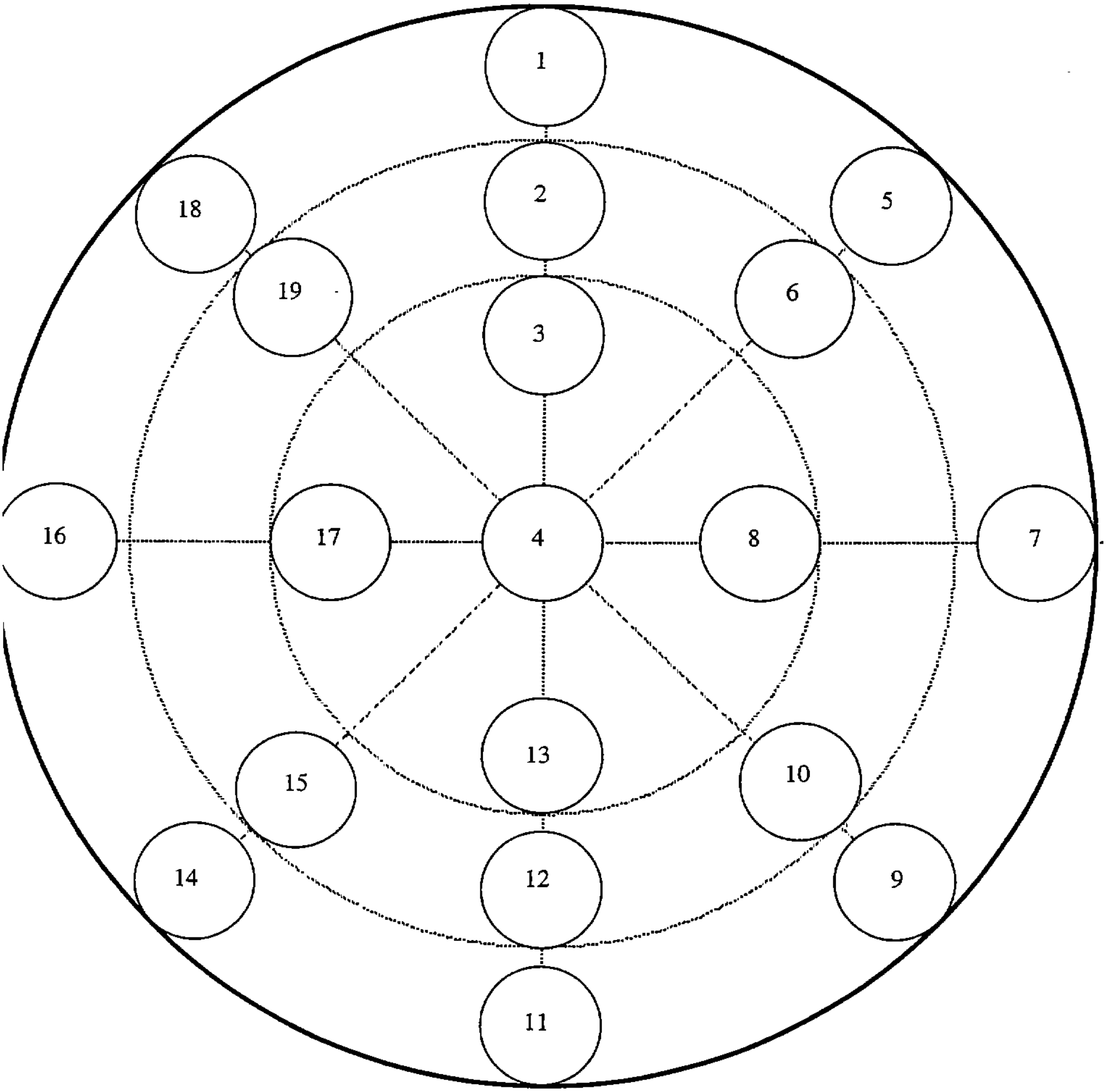
12%

25%

50%

75%

Appendix 4. The diagram that was used to assist sub-sampling of canopy invertebrates. A copy of the diagram was placed under a large petrie dish (the same diameter as the largest circle on the diagram). The smaller, numbered (1 - 19) circles show the locations of potential sub-sampling points. Eight of these 19 points were randomly chosen to sub-sample, with a 20mm diameter quadrat, each sample of canopy invertebrates.



Appendix 5. Decline index by mix of tree type.

decline index:

1 - all trees healthy
2 - some brown or purple leaves visible
3 - many brown or purple leaves & some branchlets defoliated
4 - nearly all/all leaves brown &/or major defoliation
5 - old defoliation with regrowth occurring

tree mix:

1 - all saplings
2 - saplings & young trees
3 - young trees only
4 - saplings, young & mature trees
5 - saplings & mature trees
6 - young & mature trees
7 - all mature trees

1. Banks of Swan (surveyed on foot)

1(a). All categories

Decline	Types of trees						
index	1	2	3	4	5	6	7
1		1		4		1	12
2		1		5	3	5	8
3		2		5	2	3	4
4		1		2	1	1	6
5							6

1(b). Mature trees v. mixtures

Decline	Types of trees	
index	2,4,5&6	7
1	6	12
2	14	8
3	12	4
4	5	6
5		6

1(c). Mature v. mixtures with combined decline categori

Decline	Types of trees	
index	2,4,5&6	7
1	6	12
2	14	8
3	12	10
4&5	5	12

Chi-square analysis of 1(c)

Observed				Expected			O - E		
Decline	Types of trees			Decline	Types of trees		Decline	Types of trees	
index	2,4,5&6	7		index	2,4,5&6	7	index	2,4,5&6	7
1	6	12	18	1	9.1	8.9	1	-3.1	3.1
2	14	8	22	2	11.2	10.8	2	2.8	-2.8
3	12	4	16	3	8.1	7.9	3	3.9	-3.9
4&5	5	12	17	4&5	8.6	8.4	4&5	-3.6	3.6
	37	36	73						

(O - E)sq./E

Decline	Types of trees	
index	2,4,5&6	7
1	1.053	1.083
2	0.703	0.723
3	1.876	1.928
4&5	1.504	1.546

Chi square = 10.415 3 df. P < 0.02

Conclusion: Excesses of mature trees in categories 1 & 4/5 and deficiency in cat. 3.

Appendix 5. (cont.)

2. Floodplain SE of confluence of Helena & Swan

2(a). All categories

Decline	Types of trees						
index	1	2	3	4	5	6	7
1							
2	1				1	1	
3					5		5
4					1		
5							1

2(b). Mature trees v. mixtures

Decline	Types of trees	
index	2,4,5&6	7
2	3	0
3	5	5
4	1	0
5	0	1

Conclusion: Numbers too small for Chi-square test.

3. Banks of Swan assessed by boat

3(a). All categories

Decline	Types of trees						
index	1	2	3	4	5	6	7
1							6
2					1		1
3					1		1
4				3			3
5						1	2

3(b). Mature trees v. mixtures

Decline	Types of trees	
index	2,4,5&6	7
1	0	6
2	1	1
3	1	1
4	3	3
5	1	2

3(c). Mature v. mixtures with combined decline categories

Decline	Types of trees	
index	2,4,5&6	7
1	0	6
2 to 5	6	7

Conclusion: Numbers too small for Chi-square test, suggestion of an excess of mature trees in Decline category 1.

Appendix 6. Decline index by understorey type.

decline index:

1 - all trees healthy
2 - some brown or purple leaves visible
3 - many brown or purple leaves & some branchlets defoliated
4 - nearly all/all leaves brown &/or major defoliation
5 - old defoliation with regrowth occurring

understorey/groundcover

1 - native vegetation
2 - native vegetation and weeds
3 - mainly weeds
4 - mown grass
5 - other

1. Banks of Swan (surveyed on foot)

1(a). All categories

Decline	**Type of Understorey/Groundcover**				
index	**1**	**2**	**3**	**4**	**5**
1		6	6	6	
2		2	13	7	
3			8	6	
4			6	6	
5		1	1	4	

1(b). Combining categories & removing blank categories

Decline	**Understorey/Groundcover**		
index	**2**	**3**	**4**
1	6	6	6
2	2	13	7
3, 4 & 5	1	15	16

Chi-square analysis of 1(b)

Observed

Decline	**U'storey/Groundcover**			
index	**2**	**3**	**4**	
1	6	6	6	18
2	2	13	7	22
3, 4 & 5	1	15	16	32
	9	34	29	72

Expected

Decline	**U'storey/Groundcover**		
index	**2**	**3**	**4**
1	2.3	8.5	7.3
2	2.8	10.4	8.9
3, 4 & 5	4.0	15.1	12.9

O - E

Decline	**U'storey/Groundcover**		
index	**2**	**3**	**4**
1	3.7	-2.5	-1.3
2	-0.8	2.6	-1.9
3, 4 & 5	-3.0	-0.1	3.1

(O - E)sq./E

Decline	**U'storey/Groundcover**		
index	**2**	**3**	**4**
1	6.08	0.74	0.23
2	0.23	0.65	0.41
3, 4 & 5	2.25	0.00	0.75

Chi square = 11.340 4 df : $p < 0.03$
significant

Conclusion: Excess of Decline category 1 over native vegetation with weeds.

Appendix 6. (cont.)

2. Floodplain SE of confluence of Helena & Swan

2(a). All categories

Decline	**Type of Understorey/Groundcover**				
index	**1**	**2**	**3**	**4**	**5**
2			3		
3			10		
4			1		
5			1		

Conclusion: Lack of difference in u/s makes it impossible to conclude anything

3. Banks of Swan assessed by boat

3(a). All categories

Decline	**Type of Understorey/Groundcover**				
index	**1**	**2**	**3**	**4**	**5**
1			5	1	
2			2		
3			2		
4			5		
5			3	1	

Conclusion: Lack of difference in u/s makes it impossible to conclude anything.

Appendix 7. Decline index by use of area.

decline index:

1 - all trees healthy
2 - some brown or purple leaves visible
3 - many brown or purple leaves & some branchlets defoliated
4 - nearly all/all leaves brown &/or major defoliation
5 - old defoliation with regrowth occurring

use of area

1 - little obvious use
2 - low key recreation
3 - intensive recreation/park
4 - grazing
5 - other

1. Banks of Swan (surveyed on foot)

1(a). All categories

Decline	**Use category**				
index	**1**	**2**	**3**	**4**	**5**
1	3	10	5		
2	6	12	3		
3	4	9	2		
4	5	6	1		
5		2	3		1

1(b). Combining categories & removing blank categories

Decline	**Use category**		
index	**1**	**2**	**3 & 5**
1	3	10	5
2	6	12	3
3	4	9	2
4&5	5	8	5

Chi-square analysis of 1(b)

Observed

Decline	**Use category**			
index	**1**	**2**	**3 & 5**	
1	3	10	5	18
2	6	12	3	21
3	4	9	2	15
4&5	5	8	5	18
	18	39	15	72

Expected

Decline	**Use category**		
index	**1**	**2**	**3 & 5**
1	4.5	9.8	3.8
2	5.3	11.4	4.4
3	3.8	8.1	3.1
4&5	4.5	9.8	3.8

O - E

Decline	**Use category**		
index	**1**	**2**	**3 & 5**
1	-1.5	0.2	1.2
2	0.7	0.6	-1.4
3	0.2	0.9	-1.1
4&5	0.5	-1.8	1.2

(O - E)sq./E

Decline	**Use category**		
index	**1**	**2**	**3 & 5**
1	0.50	0.00	0.38
2	0.09	0.03	0.45
3	0.01	0.10	0.39
4&5	0.06	0.33	0.38

Chi square = 2.731 p >0.8 not significant

NB. Many expected values < 5 therefore validity in doubt

Conclusion: No association between type of use and tree decline.

Appendix 7. (cont.)

2. Floodplain SE of confluence of Helena & Swan

2(a). All categories

Decline	Use category				
index	1	2	3	4	5
1					
2		3			
3		10			
4		1			
5		1			

Conclusion: None. (Lack of difference in use makes it impossible to conclude anything.)

3. Banks of Swan assessed by boat

3(a). All categories

Decline	Use category				
index	1	2	3	4	5
1	1		1	4	
2	1			1	
3				2	
4	1	1	1	3	
5		1	1	1	

3(b). Combining categories & removing blank categories

Decline	Use category	
index	1,2&3	4
1	2	4
2&3	1	3
4	3	3
5	2	1

Conclusion: None. (Numbers in each category too small to conclude anything.)

Appendix 8. Decline index by backing land use.

decline index:	**backing land use**
1 - all trees healthy	1 - native vegetation
2 - some brown or purple leaves visible	2 - grassland
3 - many brown or purple leaves & some branchlets defoliated	3 - park
4 - nearly all/all leaves brown &/or major defoliation	4 - grazing
5 - old defoliation with regrowth occurring	5 - farming/horticulture
	6 - housing
	7 - roadway
	8 - industrial
	9 - other

1. Banks of Swan (surveyed on foot)

1(a). All categories

Decline	**Backing land use category**								
index	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	1	3	8			5			1
2		6	7			4	2		3
3		5	5			4			1
4		5	2			3	2		
5			1			3	2		

1(b). Combining categories & removing blank categories

Decline	**Backing land use**	
index	**1,2&3**	**6,7&9**
1	12	6
2	13	9
3	10	5
4&5	8	10

Chi-square analysis of 1(b)

Observed

Decline	**Backing land use**		
index	**1,2&3**	**6,7&9**	
1	12	6	18
2	13	9	22
3	10	5	15
4&5	8	10	18
	43	30	73

Expected

Decline	**Backing land use**	
index	**1,2&3**	**6,7&9**
1	10.6	7.4
2	13.0	9.0
3	8.8	6.2
4&5	10.6	7.4

O - E

Decline	**Backing land use**	
index	**1,2&3**	**6,7&9**
1	1.4	-1.4
2	0.0	0.0
3	1.2	-1.2
4&5	-2.6	2.6

(O - E)sq./E

Decline	**Backing land use**	
index	**1,2&3**	**6,7&9**
1	0.185	0.265
2	0.000	0.000
3	0.163	0.234
4&5	0.638	0.914

Chi square = 2.398 p = 0.50 not significant

Conclusion: No association between backing land use and tree decline.

Appendix 8. (cont.)

2. Floodplain SE of confluence of Helena & Swan

2(a). All categories

Decline	Backing land use category								
index	1	2	3	4	5	6	7	8	9
1									
2		3							
3		9				1			
4		1							
5		1							

Conclusion: Too little variation in land use categories to make any conclusion.

3. Banks of Swan assessed by boat

3(a). All categories

Decline	Backing land use category								
index	1	2	3	4	5	6	7	8	9
1			1	5					
2				3		1			
3				2					
4				4		1			
5				1		2			

Conclusion: Too little variation in land use categories to make any conclusion.

Appendix 9. Leaf data collected from knockdown trees at three sites.

Whiteman Park - Site 1

Tree	Tree	Branch	Leaf Area (sq.cm.)			Necrosis*	No. of	Lerps	Tree	Tree	Branch	Leaf Area (sq.cm.)			Necrosis*	No. of	Lerps
Type	No.	No.	Actual	Projected	Loss	Category	Lerps	/10cm^2	Type	No.	No.	Actual	Projected	Loss	Category	Lerps	/10cm^2
Healthy	1	A	72.1	74.3	2.2	1	136	9.4	Declining	11	A	126.5	131.9	5.4	1	356	14.1
		B	75.6	75.9	0.3	1	27	1.8			B	175.6	187.2	11.6	2	403	11.5
		C	56.0	58.0	2.0	1	7	0.6			C	98.3	102.3	4.0	2	3	0.2
		D	68.0	68.9	0.9	1	22	1.6			D	89.0	91.0	2.0	2	333	18.7
		E	75.8	86.0	10.2	1	6	0.4			E	114.3	128.8	14.5	2	170	7.4
		Total	347.5	363.1	15.6	5	198	13.9			Total	603.7	641.2	37.5	9	1265	51.8
	2	A	57.8	62.2	4.4	1	12	1.0		12	A	78.4	83.1	4.7	2	94	6.0
		B	66.2	68.6	2.4	1	5	0.4			B	82.4	82.5	0.1	2	65	3.9
		C	79.5	82.1	2.6	2	26	1.6			C	52.0	52.5	0.5	1	91	8.8
		D	71.4	76.5	5.1	1	39	2.7			D	56.8	56.9	0.1	2	74	6.5
		E	82.2	88.2	6.0	1	29	1.8			E	95.3	105.6	10.3	5 F	57	3.0
		Total	357.1	377.6	20.5	6	111	7.5			Total	364.9	380.6	15.7	12	381	28.2
	3	A	95.6	97.9	2.3	2	0	0.0		13	A	123.3	125.7	2.4	2	99	4.0
		B	106.9	109.9	3.0	1	192	9.0			B	35.4	73.6	38.2	2	0	0.0
		C	112.0	113.9	1.9	2	207	9.2			C	98.2	98.8	0.6	2	213	10.8
		D	73.3	79.9	6.6	2	27	1.8			D	111.8	112.4	0.6	1	282	12.6
		E	87.9	98.1	10.2	2	97	5.5			E	75.9	82.3	6.4	2	15	1.0
		Total	475.7	499.7	24.0	9	523	25.6			Total	444.6	492.8	48.2	9	609	28.5
	4	A	113.1	118.9	5.8	3 Sk,B	55	2.4		14	A	93.9	99.3	5.4	2	0	0.0
		B	71.2	74.1	2.9	2	114	8.0			B	164.6	168.0	3.4	1	424	12.9
		C	90.4	95.6	5.2	1	30	1.7			C	121.7	123.3	1.6	1	278	11.4
		D	86.4	86.8	0.4	1	65	3.8			D	106.6	116.5	9.9	3 Sk	41	1.9
		E	101.7	102.7	1.0	2	91	4.5			E	108.5	112.9	4.4	1	165	7.6
		Total	462.8	478.1	15.3	9	355	20.3			Total	595.3	620.0	24.7	8	908	33.8
	5	A	142.4	153.2	10.8	1	31	1.1		15	A	65.0	65.4	0.4	3 B,F	30	2.3
		B	133.7	169.3	35.6	2	106	4.0			B	57.1	57.6	0.5	2	263	23.0
		C	92.0	96.6	4.6	2	68	3.7			C	56.4	58.7	2.3	1	218	19.3
		D	105.3	115.7	10.4	1	116	5.5			D	50.1	51.5	1.4	1	337	33.6
		E	127.8	136.6	8.8	1	30	1.2			E	78.9	79.1	0.2	4 F	0	0.0
		Total	601.2	671.4	70.2	7	351	15.4			Total	307.5	312.3	4.8	11	848	78.3
Total			2244.3	2389.9	145.6	36	1538	82.7	Total			2316.0	2446.9	130.9	49	4011	220.6
Average			89.77	95.60	5.82	1.44	61.52	3.3	Average			92.64	97.88	5.24	1.96	160.44	8.8

* Categories: 1=3%; 2=6%; 3=12%, 4=25%, 5=50% and 6=75%. Sk - skeletoniser damage; B - blister damage; F - fungal infection; M - leaf miner damage; U - cause unknown.

Appendix 9. (cont.)

Whiteman Park - Site 2

Tree	Tree	Branch	Leaf Area (sq.cm.)			Necrosis*	No. of	Lerps	Tree	Tree	Branch	Leaf Area (sq.cm.)			Necrosis*	No. of	Lerps
Type	No.	No.	Actual	Projected	Loss	Category	Lerps	/10cm^2	Type	No.	No.	Actual	Projected	Loss	Category	Lerps	/10cm^2
Healthy	6	A	50.3	50.5	0.2	2	69	6.9	Declining	16	A	55.6	58.3	2.7	3 U	77	6.9
		B	29.0	35.4	6.4	5 U	11	1.9			B	46.9	47.0	0.1	2	110	11.7
		C	49.7	49.8	0.1	6 U	0	0.0			C	97.2	100.1	2.9	2	272	14.0
		D	37.4	46.5	9.1	3 U	14	1.9			D	30.1	33.1	3.0	3	139	23.1
		E	32.9	35.1	2.2	2	12	1.8			E	76.6	82.2	5.6	2	248	16.2
		Total	199.3	217.3	18.0	18	106	12.5			Total	306.4	320.7	14.3	12	846	71.9
	7	A	66.9	72.0	5.1	2	1	0.1		17	A	59.1	61.0	1.9	3 Sk	0	0.0
		B	73.9	79.8	5.9	2	42	2.8			B	50.3	52.4	2.1	2	7	0.7
		C	60.9	72.1	11.2	2	10	0.8			C	91.8	110.7	18.9	4	508	27.7
		D	75.3	83.1	7.8	2	75	5.0			D	75.9	80.4	4.5	6 U	183	12.1
		E	44.0	47.4	3.4	6	0	0.0			E	77.4	89.8	12.4	4 F	324	20.9
		Total	321.0	354.4	33.4	14	128	8.7			Total	354.5	394.3	39.8	19	1022	61.4
	8	A	44.6	48.9	4.3	1	27	3.0		18	A	36.4	42.8	6.4	2	230	31.6
		B	62.5	64.7	2.2	2	6	0.5			B	55.8	59.0	3.2	2	77	6.9
		C	76.9	79.0	2.1	2	4	0.3			C	59.8	61.9	2.1	2	468	39.1
		D	58.3	62.2	3.9	2	0	0.0			D	42.0	47.8	5.8	6 U	169	20.1
		E	45.0	55.9	10.9	4 F	0	0.0			E	56.4	56.5	0.1	2	0	0.0
		Total	287.3	310.7	23.4	11	37	3.8			Total	250.4	268.0	17.6	14	944	97.7
	9	A	63.3	68.9	5.6	2	2	0.2		19	A	26.4	29.5	3.1	1	0	0.0
		B	51.9	53.3	1.4	2	0	0.0			B	65.5	70.8	5.3	2	0	0.0
		C	43.2	45.4	2.2	2	0	0.0			C	84.6	92.6	8.0	2	0	0.0
		D	29.6	38.8	9.2	3 U	0	0.0			D	53.0	70.8	17.8	6 U	67	6.3
		E	60.2	62.0	1.8	2	1	0.1			E	43.6	44.1	0.5	2	0	0.0
		Total	248.2	268.4	20.2	11	3	0.2			Total	273.1	307.8	34.7	13	67	6.3
	10	A	52.6	58.3	5.7	2	2	0.2		20	A	46.4	56.1	9.7	5 U	99	10.7
		B	70.5	70.5	0.0	3 F	0	0.0			B	54.7	66.1	11.4	6 F,U	103	9.4
		C	42.4	44.8	2.4	2	3	0.4			C	83.8	93.4	9.6	6 F	32	1.9
		D	53.6	53.8	0.2	2	0	0.0			D	68.5	78.4	9.9	3 F	127	9.3
		E	33.1	40.2	7.1	2	0	0.0			E	66.2	73.5	7.3	2	71	5.4
		Total	252.2	267.6	15.4	11	5	0.5			Total	319.6	367.5	47.9	22	432	36.6
Total			1308.0	1418.4	110.4	65	279	25.7	Total			1504.0	1658.3	154.3	80	3311	274.0
Average			52.32	56.74	4.42	2.60	11.16	1.0	Average			60.16	66.33	6.17	3.20	132.44	11.0

* Categories: 1=3%; 2=6%; 3=12%; 4=25%; 5=50% and 6=75%. Sk - skeletoniser damage; B - blister damage; F - fungal infection; M - leaf miner damage; U - cause unknown.

Appendix 9. (cont.)

Guildford

Tree	Tree	Branch	Leaf Area (sq.cm.)			Necrosis*	No. of	Lerps	Tree	Tree	Branch	Leaf Area (sq.cm.)			Necrosis*	No. of	Lerps
Type	No.	No.	Actual	Projected	Loss	Category	Lerps	/10cm^2	Type	No.	No.	Actual	Projected	Loss	Category	Lerps	/10cm^2
Healthy	21	A	41.2	46.6	5.4	3 M	8	1.0	Declining	34	A	40.3	40.6	0.3	2	70	8.7
		B	48.2	54.5	6.3	6 M	3	0.3			B	50.7	53.9	3.2	2	48	4.7
		C	23.2	44.8	21.6	3 M	1	0.2			C	70.8	77.7	6.9	2	74	5.2
		D	28.8	46.9	18.1	5 M	14	2.4			D	54.8	64.1	9.3	2	60	5.5
		E	64.2	70.6	6.4	2	143	11.1			E	34.6	46.1	11.5	3	63	9.1
		Total	205.6	263.4	57.8	19	169	15.1			Total	251.2	282.4	31.2	11	315	33.2
	22	A	76.1	76.7	0.6	2	6	0.4		35	A	48.1	66.6	18.5	3 M	46	4.8
		B	58.1	62.9	4.8	2	7	0.6			B	44.2	48.1	3.9	2	27	3.1
		C	55.1	56.2	1.1	2	0	0.0			C	33.9	52.7	18.8	2	6	0.9
		D	84.1	84.2	0.1	2	10	0.6			D	140.9	154.6	13.7	3 M,U	18	0.6
		E	42.3	42.6	0.3	2	5	0.6			E	64.1	72.4	8.3	4 M	43	3.4
		Total	315.7	322.6	6.9	10	28	2.2			Total	331.2	394.4	63.2	14	140	12.7
	23	A	24.5	24.8	0.3	1	0	0.0		36	A	71.6	90.5	18.9	5 M	15	1.0
		B	29.4	33.8	4.4	3	0	0.0			B	44.9	52.6	7.7	2	22	2.4
		C	74.9	82.7	7.8	3 F	0	0.0			C	32.6	37.9	5.3	2	17	2.6
		D	14.6	18.2	3.6	3 U	0	0.0			D	73.2	80.9	7.7	2	99	6.8
		E	80.1	89.1	9.0	3 F	0	0.0			E	76.7	79.4	2.7	2	88	5.7
		Total	223.5	248.6	25.1	13	0	0.0			Total	299.0	341.3	42.3	13	241	18.6
	25	A	63.9	76.6	12.7	2	82	6.4		37	A	37.8	39.0	1.2	2	9	1.2
		B	64.7	69.7	5.0	2	18	1.4			B	35.6	35.9	0.3	1	18	2.5
		C	86.0	91.8	5.8	3 M	0	0.0			C	43.8	44.4	0.6	2	10	1.1
		D	78.5	103.1	24.6	3 M	0	0.0			D	33.1	37.3	4.2	4 M,U	3	0.5
		E	24.1	47.1	23.0	2	11	2.3			E	38.4	40.8	2.4	2	21	2.7
		Total	317.2	388.3	71.1	12	111	10.1			Total	188.7	197.4	8.7	11	61	8.0
	27	A	23.5	49.2	25.7	4 U	6	1.3		38	A	90.0	93.8	3.8	2	61	3.4
		B	68.6	68.6	0.0	4 F	0	0.0			B	48.7	55.6	6.9	3	24	2.5
		C	29.0	34.9	5.9	5 F,U	0	0.0			C	37.8	38.6	0.8	2	67	8.9
		D	52.7	55.8	3.1	2	11	1.0			D	27.4	27.9	0.5	2	0	0.0
		E	62.9	74.4	11.5	3 M,U	1	0.1			E	21.4	21.7	0.3	2	66	15.4
		Total	236.7	282.9	46.2	18	18	2.4			Total	225.3	237.6	12.3	11	218	30.1
Total			1298.7	1505.8	207.1	72	326	29.7	Total			1295.4	1453.1	157.7	60	975	102.7
Average			51.95	60.23	8.28	2.88	13.04	1.2	Average			51.82	58.12	6.31	2.40	39.00	4.1

* Categories: 1=3%; 2=6%; 3=12%; 4=25%; 5=50% and 6=75%. Sk - skeletoniser damage; B - blister damage; F - fungal infection; M - leaf miner damage; U - cause unknown.

Appendix 10. Chi-square analysis of associations between tree type and necrosis category.

Whiteman Park - Site 1

Tree Type	**Necrosis Category***					
	1	**2**	**3**	**4**	**5**	**6**
Healthy	15	9	1	0	0	0
Declining	8	13	2	1	1	0

* See Appendix 9 for explanation.

Observed

Tree Type	**Necrosis Category***		
	1	**2,3,4 &5**	**Total**
Healthy	15	10	25
Declining	8	17	25
Total	23	27	50

Expected

Tree Type	**Necrosis Category***	
	1	**2,3,4 &5**
Healthy	11.5	13.5
Declining	11.5	13.5

Obs. - Exp.

Tree Type	**Necrosis Category***	
	1	**2,3,4 &5**
Healthy	3.5	-3.5
Declining	-3.5	3.5

Chi square = 3.95 (1 degree of freedom; $p < 0.05$)

Whiteman Park – Site 2

Tree Type	**Necrosis Category***					
	1	**2**	**3**	**4**	**5**	**6**
Healthy	1	17	3	1	1	2
Declining	1	12	4	2	1	5

* See Appendix 9 for explanation.

Observed

Tree Type	**Necrosis Category***		
	1&2	**3,4,5 &6**	**Total**
Healthy	18	7	25
Declining	13	12	25
Total	31	19	50

Expected

Tree Type	**Necrosis Category***	
	1	**2,3,4 &5**
Healthy	15.5	9.5
Declining	15.5	9.5

Obs. - Exp.

Tree Type	**Necrosis Category***	
	1&2	**3,4,5 &6**
Healthy	2.5	-2.5
Declining	-2.5	2.5

Chi square = 2.12 (1 degree of freedom; $p > 0.10$)

Observed

Tree Type	**Necrosis Category***		
	1,2&3	**4,5 &6**	**Total**
Healthy	21	4	25
Declining	17	8	25
Total	38	12	50

Expected

Tree Type	**Necrosis Category***	
	1	**2,3,4 &5**
Healthy	19	6
Declining	19	6

Obs. - Exp.

Tree Type	**Necrosis Category***	
	1,2&3	**4,5 &6**
Healthy	2	-2
Declining	-2	2

Chi square = 1.75 (1 degree of freedom; $p > 0.10$)

Appendix 10 (cont.)

Guildford

Tree Type	Necrosis Category*					
	1	2	3	4	5	6
Healthy	1	10	9	2	2	1
Declining	1	17	4	2	1	0

* See Appendix 9 for explanation.

Observed

Tree Type	Necrosis Category*		
	1&2	3,4,5 &6	Total
Healthy	11	14	25
Declining	18	7	25
Total	29	21	50

Expected

Tree Type	Necrosis Category*	
	1	2,3,4 &5
Healthy	14.5	10.5
Declining	14.5	10.5

Obs. - Exp.

Tree Type	Necrosis Category*	
	1&2	3,4,5 &6
Healthy	-3.5	3.5
Declining	3.5	-3.5

Chi square = 4.02 (1 degree of freedom; $p < 0.05$)

Appendix 11. Concentrations of twelve nutrients in leaves of thirty trees used to sample invertebrates. (Trees 1 -5 and 11 - 15 were at Whiteman Park Site1, and trees 6 - 10 and 16 - 20 were at Whiteman Park Site 2. The remaining trees were at Guildford. At each site healthy trees were assigned lower numbers than those of the declining trees.)

Tree Number	Concentration in %							Concentration in ppm.				
	N	P	K	S	Na	Ca	Mg	Cu	Zn	Mn	Fe	B
1	1.80	0.12	0.58	0.14	0.26	0.91	0.24	4.4	38.2	109	82	70.6
2	1.87	0.09	0.50	0.16	0.28	0.81	0.23	5.6	43.7	96	62	55.7
3	2.16	0.13	0.76	0.19	0.44	0.76	0.17	3.7	18.1	88	73	56.8
4	1.39	0.08	0.98	0.15	0.34	0.58	0.19	3.6	42.3	49	41	39.3
5	1.72	0.10	0.72	0.16	0.41	0.54	0.17	4.2	23.6	52	47	38.9
6	2.01	0.15	0.65	0.17	0.24	0.32	0.12	4.3	21.0	46	47	38.6
7	1.75	0.14	0.79	0.15	0.27	0.35	0.11	4.5	22.4	52	46	39.2
8	2.14	0.20	0.65	0.16	0.33	0.39	0.24	4.3	27.7	36	45	40.6
9	2.13	0.17	0.63	0.18	0.39	0.40	0.17	3.5	16.2	38	64	42.4
10	1.74	0.12	0.62	0.12	0.29	0.34	0.18	3.1	26.1	120	48	18.9
11	1.38	0.19	0.92	0.14	0.28	0.93	0.21	3.5	25.1	61	41	48.8
12	1.91	0.22	0.97	0.18	0.37	1.04	0.27	4.4	27.0	98	61	61.8
13	1.75	0.14	0.61	0.14	0.42	0.88	0.21	5.5	48.1	94	36	33.8
14	2.04	0.17	1.00	0.21	0.36	0.73	0.19	10.9	45.9	321	55	46.3
15	1.96	0.12	0.84	0.18	0.38	0.46	0.20	3.8	16.2	180	89	51.0
16	2.21	0.21	0.77	0.17	0.29	0.69	0.18	4.6	19.6	81	59	38.9
17	2.05	0.15	1.00	0.17	0.33	0.65	0.21	2.3	27.9	53	83	45.3
18	2.06	0.14	0.67	0.19	0.36	0.47	0.15	3.5	21.1	64	99	48.7
19	2.06	0.15	0.50	0.15	0.21	0.66	0.13	4.3	30.3	77	75	45.8
20	2.00	0.26	1.27	0.19	0.36	0.55	0.20	3.7	21.7	101	73	41.5
21	1.73	0.11	0.80	0.17	0.24	0.57	0.20	12.0	27.2	914	89	62.5
22	1.59	0.10	0.68	0.14	0.22	0.38	0.14	9.2	26.1	732	54	48.8
23	1.74	0.10	0.50	0.13	0.20	0.44	0.17	9.7	32.3	1042	37	57.8
25	1.77	0.09	0.53	0.14	0.15	0.73	0.19	10.1	25.0	1896	56	58.6
27	1.69	0.09	0.57	0.14	0.21	0.55	0.29	8.1	22.7	938	38	32.0
34	1.46	0.16	0.57	0.17	0.41	0.58	0.29	4.4	13.5	604	67	61.7
35	1.27	0.11	0.55	0.18	0.41	0.57	0.22	3.9	20.8	626	65	44.5
36	1.72	0.13	0.45	0.15	0.18	0.65	0.28	4.4	16.8	1736	65	67.2
37	1.46	0.13	0.52	0.15	0.31	0.60	0.27	4.6	19.7	863	45	62.3
38	1.90	0.14	0.42	0.19	0.38	0.59	0.20	8.5	19.7	1109	43	59.8

Appendix 12. Estimated total numbers and percentages of invertebrates in in each group and for each tree at Whiteman Park - Sites 1 & 2.

Whiteman Park - Site 1 (WP1)

WP1 - Total Number of Invertebrates Estimated by Sub-sampling

	Tree Number										
Class, etc.	**1**	**2**	**3**	**4**	**5**	**11**	**12**	**13**	**14**	**15**	**Total**
Acarina (mites)	93	84	105	369	190	42	21	0	63	179	1146
Araneae (spiders)	72	95	137	84	168	21	10	21	42	168	818
Coleoptera (beetles) - adults	216	284	600	200	126	221	116	0	158	663	2584
- larvae	22	74	179	21	74	21	21	0	21	168	601
Collembola	748	190	0	21	95	0	0	0	42	32	1128
Diptera (flies)	618	1158	695	663	242	1148	84	200	211	1179	6198
Heteroptera (bugs) - adults	29	32	63	21	11	63	0	11	21	95	346
- nymphs	36	32	0	21	0	0	0	21	0	42	152
Auchenorrhyncha - adults	266	411	453	548	295	190	32	116	42	642	2995
(leaf hoppers) - nymphs	316	400	358	421	211	137	221	200	179	895	3338
Sternorrhyncha - adults	12295	12615	15721	9582	4675	8982	1485	3675	4833	16606	90469
(psyllids) -nymphs	194	305	453	211	105	263	453	74	295	421	2774
Vespoidea (wasps)	1438	1832	937	1632	927	1590	95	463	369	2748	12031
Thysanoptera (thrips)	906	1537	1611	979	853	284	211	211	569	1601	8762
Others	36	42	11	21	32	74	42	0	32	105	395
Unidentified	86	211	42	53	0	0	0	0	0	84	476
Too damaged to ID	151	242	53	32	11	95	21	21	95	126	847
Total No.of Individuals	**17522**	**19544**	**21418**	**14879**	**8015**	**13131**	**2812**	**5013**	**6972**	**25754**	
Total No.of Individuals (excl. adult psyllids)	**5227**	**6929**	**5697**	**5297**	**3340**	**4149**	**1327**	**1338**	**2139**	**9148**	

WP1 - Total Number of Invertebrates per cubic metre of canopy - Estimated by Sub-sampling

	Tree Number										
Class, etc.	**1**	**2**	**3**	**4**	**5**	**11**	**12**	**13**	**14**	**15**	**Total**
Acarina (mites)	5.3	5.3	8.0	51.3	18.6	5.8	4.7	0.0	8.8	13.4	121.0
Araneae (spiders)	4.1	5.9	10.5	11.7	16.5	2.9	2.2	3.1	5.8	12.5	75.3
Coleoptera (beetles) - adults	12.3	17.8	45.8	27.8	12.4	30.7	25.8	0.0	21.9	49.5	243.8
- larvae	1.3	4.6	13.7	2.9	7.3	2.9	4.7	0.0	2.9	12.5	52.7
Collembola	42.5	11.9	0.0	2.9	9.3	0.0	0.0	0.0	5.8	2.4	74.8
Diptera (flies)	35.1	72.4	53.1	92.1	23.7	159.4	18.7	29.9	29.3	88.0	601.6
Heteroptera (bugs) - adults	1.6	2.0	4.8	2.9	1.1	8.8	0.0	1.6	2.9	7.1	32.8
- nymphs	2.0	2.0	0.0	2.9	0.0	0.0	0.0	3.1	0.0	3.1	13.2
Auchenorrhyncha - adults	15.1	25.7	34.6	76.1	28.9	26.4	7.1	17.3	5.8	47.9	285.0
(leaf hoppers) - nymphs	18.0	25.0	27.3	58.5	20.7	19.0	49.1	29.9	24.9	66.8	339.1
Sternorrhyncha - adults	698.6	788.4	1200.1	1330.8	458.3	1247.5	330.0	548.5	671.3	1239.3	8512.8
(psyllids) -nymphs	11.0	19.1	34.6	29.3	10.3	36.5	100.7	11.0	41.0	31.4	324.9
Vespoidea (wasps)	81.7	114.5	71.5	226.7	90.9	220.8	21.1	69.1	51.3	205.1	1152.7
Thysanoptera (thrips)	51.5	96.1	123.0	136.0	83.6	39.4	46.9	31.5	79.0	119.5	806.4
Others	2.0	2.6	0.8	2.9	3.1	10.3	9.3	0.0	4.4	7.8	43.5
Unidentified	4.9	13.2	3.2	7.4	0.0	0.0	0.0	0.0	0.0	6.3	34.9
Too damaged to ID	8.6	15.1	4.0	4.4	1.1	13.2	4.7	3.1	13.2	9.4	76.9
Total No.of Individuals	**995.6**	**1221.5**	**1635.0**	**2066.5**	**785.8**	**1823.8**	**624.9**	**748.2**	**968.3**	**1921.9**	
Total No.of Individuals (excl. adult psyllids)	**297.0**	**433.1**	**434.9**	**735.7**	**327.5**	**576.3**	**294.9**	**199.7**	**297.1**	**682.7**	

Appendix 12 (cont.)

WP1 - Percentage of Invertebrates in Each Group - Estimated by Sub-sampling

	Tree Number									
Class, etc.	1	2	3	4	5	11	12	13	14	15
Acarina (mites)	0.5	0.4	0.5	2.5	2.4	0.3	0.7	0.0	0.904	0.7
Araneae (spiders)	0.4	0.5	0.6	0.6	2.1	0.2	0.4	0.4	0.6	0.7
Coleoptera (beetles) - adults	1.2	1.5	2.8	1.3	1.6	1.7	4.1	0.0	2.3	2.6
- larvae	0.1	0.4	0.8	0.1	0.9	0.2	0.7	0.0	0.3	0.7
Collembola	4.3	1.0	0.0	0.1	1.2	0.0	0.0	0.0	0.6	0.1
Diptera (flies)	3.5	5.9	3.2	4.5	3.0	8.7	3.0	4.0	3.0	4.6
Heteroptera (bugs) - adults	0.2	0.2	0.3	0.1	0.1	0.5	0.0	0.2	0.3	0.4
- nymphs	0.2	0.2	0.0	0.1	0.0	0.0	0.0	0.4	0.0	0.2
Auchenorrhyncha - adults	1.5	2.1	2.1	3.7	3.7	1.4	1.1	2.3	0.6	2.5
(leaf hoppers) - nymphs	1.8	2.0	1.7	2.8	2.6	1.0	7.9	4.0	2.6	3.5
Sternorrhyncha - adults	70.2	64.5	73.4	64.4	58.3	68.4	52.8	73.3	69.3	64.5
(psyllids) -nymphs	1.1	1.6	2.1	1.4	1.3	2.0	16.1	1.5	4.2	1.6
Vespoidea (wasps)	8.2	9.4	4.4	11.0	11.6	12.1	3.4	9.2	5.3	10.7
Thysanoptera (thrips)	5.2	7.9	7.5	6.6	10.6	2.2	7.5	4.2	8.2	6.2
Others	0.2	0.2	0.1	0.1	0.4	0.6	1.5	0.0	0.5	0.4
Unidentified	0.5	1.1	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.3
Too damaged to ID	0.9	1.2	0.2	0.2	0.1	0.7	0.7	0.4	1.4	0.5

WP1 - % of Invertebrates (excluding adult psyllids) in Each Group - Estimated by Sub-sampling

Class, etc.	Tree Number									
	1	2	3	4	5	11	12	13	14	15
Acarina (mites)	1.8	1.2	1.8	7.0	5.7	1.0	1.6	0.0	2.9	2.0
Araneae (spiders)	1.4	1.4	2.4	1.6	5.0	0.5	0.8	1.6	2.0	1.8
Coleoptera (beetles) - adults	4.1	4.1	10.5	3.8	3.8	5.3	8.7	0.0	7.4	7.2
- larvae	0.4	1.1	3.1	0.4	2.2	0.5	1.6	0.0	1.0	1.8
Collembola	14.3	2.7	0.0	0.4	2.8	0.0	0.0	0.0	2.0	0.3
Diptera (flies)	11.8	16.7	12.2	12.5	7.2	27.7	6.3	14.9	9.9	12.9
Heteroptera (bugs) - adults	0.6	0.5	1.1	0.4	0.3	1.5	0.0	0.8	1.0	1.0
- nymphs	0.7	0.5	0.0	0.4	0.0	0.0	0.0	1.6	0.0	0.5
Auchenorrhyncha - adults	5.1	5.9	8.0	10.3	8.8	4.6	2.4	8.7	2.0	7.0
(leaf hoppers) - nymphs	6.0	5.8	6.3	7.9	6.3	3.3	16.7	14.9	8.4	9.8
Sternorrhyncha - nymphs	3.7	4.4	8.0	4.0	3.1	6.3	34.1	5.5	13.8	4.6
Vespoidea (wasps)	27.5	26.4	16.4	30.8	27.8	38.3	7.2	34.6	17.3	30.0
Thysanoptera (thrips)	17.3	22.2	28.3	18.5	25.5	6.8	15.9	15.8	26.6	17.5
Others	0.7	0.6	0.2	0.4	1.0	1.8	3.2	0.0	1.5	1.1
Unidentified	1.6	3.0	0.7	1.0	0.0	0.0	0.0	0.0	0.0	0.9
Too damaged to ID	2.9	3.5	0.9	0.6	0.3	2.3	1.6	1.6	4.4	1.4

Appendix 12 (cont.)

Whiteman Park - Site 2 (WP2)

WP2 - Total Number of Invertebrates Estimated by Sub-sampling

	Tree Number										
Class, etc.	**6**	**7**	**8**	**9**	**10**	**16**	**17**	**18**	**19**	**20**	**Total**
Acarina (mites)	263	95	200	63	21	695	42	706	295	95	2475
Araneae (spiders)	95	158	147	84	84	126	221	147	84	95	1241
Coleoptera (beetles) - adults	168	474	432	84	32	284	369	74	74	32	2023
- larvae	21	42	42	42	21	126	53	32	11	21	411
Collembola	0	21	11	32	21	84	32	21	32	21	275
Diptera (flies)	295	484	1095	347	42	390	1011	253	95	53	4065
Heteroptera (bugs) - adults	32	53	42	11	21	42	137	21	32	11	402
- nymphs	11	42	116	11	21	116	74	21	11	21	444
Auchenorrhyncha - adults	453	337	84	53	0	442	305	84	53	53	1864
(leaf hoppers) - nymphs	1337	874	758	369	105	1106	927	442	137	242	6297
Sternorrhyncha - adults	706	1506	3085	1074	137	800	3243	842	453	400	12246
(psyllids) -nymphs	158	63	221	126	53	527	221	211	105	211	1896
Vespoidea (wasps)	232	463	326	221	53	263	653	432	190	84	2917
Thysanoptera (thrips)	1200	2464	611	390	200	3222	811	621	1106	200	10825
Others	137	21	105	115	32	127	63	63	94	0	757
Unidentified	63	74	21	11	11	11	11	0	42	42	286
Too damaged to ID	21	179	105	32	11	32	63	42	84	21	590
Total No.of Individuals	**5192**	**7350**	**7401**	**3065**	**865**	**8393**	**8236**	**4012**	**2898**	**1602**	
Total No.of Individuals (excl. adult psyllids)	**4486**	**5844**	**4316**	**1991**	**728**	**7593**	**4993**	**3170**	**2445**	**1202**	

WP2 - Total Number of Invertebrates per cubic metre of canopy - Estimated by Sub-sampling

	Tree Number										
Class, etc.	**6**	**7**	**8**	**9**	**10**	**16**	**17**	**18**	**19**	**20**	**Total**
Acarina (mites)	52.6	14.4	25.0	5.8	2.7	231.7	7.1	98.1	65.6	27.1	530.0
Araneae (spiders)	19.0	23.9	18.4	7.7	10.9	42.0	37.5	20.4	18.7	27.1	225.6
Coleoptera (beetles) - adults	33.6	71.8	54.0	7.7	4.2	94.7	62.5	10.3	16.4	9.1	364.4
- larvae	4.2	6.4	5.3	3.9	2.7	42.0	9.0	4.4	2.4	6.0	86.3
Collembola	0.0	3.2	1.4	2.9	2.7	28.0	5.4	2.9	7.1	6.0	59.7
Diptera (flies)	59.0	73.3	136.9	31.8	5.5	130.0	171.4	35.1	21.1	15.1	679.2
Heteroptera (bugs) - adults	6.4	8.0	5.3	1.0	2.7	14.0	23.2	2.9	7.1	3.1	73.8
- nymphs	2.2	6.4	14.5	1.0	2.7	38.7	12.5	2.9	2.4	6.0	89.4
Auchenorrhyncha - adults	90.6	51.1	10.5	4.9	0.0	147.3	51.7	11.7	11.8	15.1	394.6
(leaf hoppers) - nymphs	267.4	132.4	94.8	33.9	13.6	368.7	157.1	61.4	30.4	69.1	1228.8
Sternorrhyncha - adults	141.2	228.2	385.6	98.5	17.8	266.7	549.7	116.9	100.7	114.3	2019.6
(psyllids) -nymphs	31.6	9.5	27.6	11.6	6.9	175.7	37.5	29.3	23.3	60.3	413.3
Vespoidea (wasps)	46.4	70.2	40.8	20.3	6.9	87.7	110.7	60.0	42.2	24.0	509.0
Thysanoptera (thrips)	240.0	373.3	76.4	35.8	26.0	1074.0	137.5	86.3	245.8	57.1	2352.1
Others	27.4	3.2	13.1	10.6	4.2	42.3	10.7	8.8	20.9	0.0	141.1
Unidentified	12.6	11.2	2.6	1.0	1.4	3.7	1.9	0.0	9.3	12.0	55.7
Too damaged to ID	4.2	27.1	13.1	2.9	1.4	10.7	10.7	5.8	18.7	6.0	100.7
Total No.of Individuals	**1038.4**	**1113.6**	**925.1**	**281.2**	**112.3**	**2797.7**	**1395.9**	**557.2**	**644.0**	**457.7**	
Total No.of Individuals (excl. adult psyllids)	**897.2**	**885.5**	**539.5**	**182.7**	**94.5**	**2531.0**	**846.3**	**440.3**	**543.3**	**343.4**	

Appendix 12 (cont.)

WP2 - Percentage of Invertebrates in Each Group - Estimated by Sub-sampling

	Tree Number									
Class, etc.	**6**	**7**	**8**	**9**	**10**	**16**	**17**	**18**	**19**	**20**
Acarina (mites)	5.1	1.3	2.7	2.1	2.4	8.3	0.5	17.6	10.2	5.9
Araneae (spiders)	1.8	2.1	2.0	2.7	9.7	1.5	2.7	3.7	2.9	5.9
Coleoptera (beetles) - adults	3.2	6.4	5.8	2.7	3.7	3.4	4.5	1.8	2.6	2.0
- larvae	0.4	0.6	0.6	1.4	2.4	1.5	0.6	0.8	0.4	1.3
Collembola	0.0	0.3	0.1	1.0	2.4	1.0	0.4	0.5	1.1	1.3
Diptera (flies)	5.7	6.6	14.8	11.3	4.9	4.6	12.3	6.3	3.3	3.3
Heteroptera (bugs) - adults	0.6	0.7	0.6	0.4	2.4	0.5	1.7	0.5	1.1	0.7
- nymphs	0.2	0.6	1.6	0.4	2.4	1.4	0.9	0.5	0.4	1.3
Auchenorrhyncha - adults	8.7	4.6	1.1	1.7	0.0	5.3	3.7	2.1	1.8	3.3
(leaf hoppers) - nymphs	25.8	11.9	10.2	12.0	12.1	13.2	11.3	11.0	4.7	15.1
Sternorrhyncha - adults	13.6	20.5	41.7	35.0	15.8	9.5	39.4	21.0	15.6	25.0
(psyllids) -nymphs	3.0	0.9	3.0	4.1	6.1	6.3	2.7	5.3	3.6	13.2
Vespoidea (wasps)	4.5	6.3	4.4	7.2	6.1	3.1	7.9	10.8	6.6	5.2
Thysanoptera (thrips)	23.1	33.5	8.3	12.7	23.1	38.4	9.8	15.5	38.2	12.5
Others	2.6	0.3	1.4	3.8	3.7	1.5	0.8	1.6	3.2	0.0
Unidentified	1.2	1.0	0.3	0.4	1.3	0.1	0.1	0.0	1.4	2.6
Too damaged to ID	0.4	2.4	1.4	1.0	1.3	0.4	0.8	1.0	2.9	1.3

WP2 - % of Invertebrates (excluding adult psyllids) in Each Group - Estimated by Sub-sampling

	Tree Number									
Class, etc.	**6**	**7**	**8**	**9**	**10**	**16**	**17**	**18**	**19**	**20**
Acarina (mites)	5.9	1.6	4.6	3.2	2.9	9.1	0.8	22.3	12.1	7.9
Araneae (spiders)	2.1	2.7	3.4	4.2	11.5	1.7	4.4	4.6	3.4	7.9
Coleoptera (beetles) - adults	3.7	8.1	10.0	4.2	4.4	3.7	7.4	2.3	3.0	2.7
- larvae	0.5	0.7	1.0	2.1	2.9	1.7	1.1	1.0	0.4	1.7
Collembola	0.0	0.4	0.3	1.6	2.9	1.1	0.6	0.7	1.3	1.7
Diptera (flies)	6.6	8.3	25.4	17.4	5.8	5.1	20.3	8.0	3.9	4.4
Heteroptera (bugs) - adults	0.7	0.9	1.0	0.6	2.9	0.6	2.7	0.7	1.3	0.9
- nymphs	0.2	0.7	2.7	0.6	2.9	1.5	1.5	0.7	0.4	1.7
Auchenorrhyncha - adults	10.1	5.8	1.9	2.7	0.0	5.8	6.1	2.7	2.2	4.4
(leaf hoppers) - nymphs	29.8	15.0	17.6	18.5	14.4	14.6	18.6	13.9	5.6	20.1
Sternorrhyncha - nymphs	3.5	1.1	5.1	6.3	7.3	6.9	4.4	6.7	4.3	17.6
Vespoidea (wasps)	5.2	7.9	7.6	11.1	7.3	3.5	13.1	13.6	7.8	7.0
Thysanoptera (thrips)	26.8	42.2	14.2	19.6	27.5	42.4	16.2	19.6	45.2	16.6
Others	3.1	0.4	2.4	5.8	4.4	1.7	1.3	2.0	3.8	0.0
Unidentified	1.4	1.3	0.5	0.6	1.5	0.1	0.2	0.0	1.7	3.5
Too damaged to ID	0.5	3.1	2.4	1.6	1.5	0.4	1.3	1.3	3.4	1.7