

RING-BARKING AND GIRDLING: HOW MUCH VASCULAR CONNECTION DO YOU NEED BETWEEN ROOTS AND CROWN?

G.M. Moore

Burnley College, University of Melbourne, 500 Yarra Boulevard, RICHMOND, 3121

Abstract

Girdling and ring-barking of trees occurs for many reasons - vehicle impact, grazing by animals, insect and fungal attack and human vandalism. Ring-barking that removes only phloem and cambial tissue has a vastly different impact on tree physiology than girdling which removes phloem, cambial and xylem tissue. Girdling has an almost immediate effect on transpiration and so plants wilt quickly and tissues can die within days. Ring-barking however effects translocation and so causes a slow starvation of the root system and can take many months or even years before root tissues start to die from starvation and the tree wilts and dies.

Many trees survive partial ring-barking, but how much of the vascular tissue needs to be intact for plants to survive and what effective treatments are available, if any, to arborists for improving the chances of tree survival? As little as 10% of vascular tissue may be all that is required for an otherwise healthy and vigorous young tree to survive and recover. Furthermore, while ring-barking and girdling may not kill a tree they may leave it vulnerable to attack from insect pests and fungal diseases.

Tree management techniques such as bridge, approach or patch grafting may be considered as remedial treatments for ring-barked or girdled trees. Soil injection of sugar solutions may also be of benefit. However, making sure that the tree is free from environmental stresses and pest and diseases are important to recovery and allowing time for the tree to produce callus and wound wood.

Introduction

It is unfortunate the terms girdling, ring barking, ring-barking, ringbarking (ring-barking with the hyphen seems to about twice as common in use as ringbarking) and even ringing are used as synonyms to refer to the removal of a band or strip of bark which contains the cork and cork cambium, phloem and usually the cambium around the entire circumference of a tree (Salisbury and Ross, 1992; Raven et al, 2005). It is unfortunate that so many terms are used for the same imprecisely specified action, as the depth to which the band of tissue is cut can markedly affect the impact on the tree's vascular system and the subsequent effect on the tree of the action.

In this paper, ring-barking will be defined as a circumferential cut made around the trunk of a tree which removes a band of tissue to the depth of an including the cambium. Such a cut removes a band which contains cork and cork cambium, phloem tissues and the cambium and so has an immediate impact on the translocation of materials in the phloem tissues. Girdling will be defined as a circumferential cut made around the trunk of a tree which removes a band of tissue to the depth of the active or functional xylem tissues. Such a cut removes a band which contains cork and cork cambium, phloem tissues, the cambium and the current season's active or functional xylem tissue growth ring and so has an immediate impact on both the translocational and transpirational processes. The only way of telling whether a tree has been ring-barked or girdled is to examine the tissues which have been severed.

Because the effects and consequences of ring-barking and girdling on trees are so different and impact on the tree over such different time scales, it would probably be wise if different terms were adopted for the different actions. Such a distinction would bring clarity of meaning to the terms, aid in diagnosis of injury to trees, avoid ambiguity, aid in defining remedial treatment and benefit the legal system in matters related to litigation involving either activity.

Causes of Ring-barking and Girdling

There are many different causes of ring-barking and girdling from both natural and human interventions (Table 1). Both ring-barking and girdling have a long history of being used as management tools in forestry and agriculture for clearing land and removing trees from paddocks (Stubbs, 1998). It is cost effective for

selectively thinning forests and plantations and for the control of invasive woody species (Kilroy and Windell, 1999). In more subtle ways, orchardists and horticulturists have used ring-barking and girdling to manipulate plant growth form, soluble sugar content and fruit yield and production, but they are careful not to completely ring-bark the whole stem or selected branch (Hartmann et al, 1981; Goren et al, 2004).

In urban arboriculture, the most common causes of ring-barking and girdling arise from accidents, poor landscape management practices and attempts to kill trees. Accidental occurrences include motor vehicle accidents and wire and other non-degradable materials tied around tree trunks. Poor landscape management practices such as girdling roots from poor propagation technique, mower and whippersnipper damage, poor staking and tree guards, and pavement and concrete surrounding trunks in paved areas can all cause serious damage. Finally, there are attempts at killing trees in disputes between neighbours and acts of deliberate vandalism (Harris et al, 2004).

Not all ring-barking and girdling damage, however, is caused by human action as animal grazing, fungal and insect attack and poor root growth habit can occur naturally. While these cases are not all that common, damage by sulphur-crested cockatoos (*Cacatua galerita*) can be extensive and cause significant structural damage to large trees. Horses have also been known to ring-bark large trees in their paddocks by grazing the bark in great strips, apparently to meet a nutrient deficiency. Insect and fungal damage to trunks and large limbs is not uncommon, but usually affects trees that are already stressed.

The physiology of Ring-barking and Girdling

Ring-barking affecting phloem tissues and transport:

The effects of ring-barking, as defined earlier, on the physiology of a tree are dramatically different from the effects of girdling. The removal of the bark and cambium only has an impact on translocation via the phloem tissues, but water and nutrient transport continues as xylem tissues are undamaged (Weier et al, 1982; Salisbury and Ross 1992). The removal of phloem tissues affects transport of complex organic molecules such as sugars, amino acids and hormones, as well as other simpler substances dissolved in the phloem sap (Holmes, 1984). Transport of these substances from roots to foliage and stem above the region ring-barked is halted but so too is transport from the foliage to the root system, especially of photosynthates and hormones.

The direction of transport through phloem tissues and its impact on tree physiology can also vary according to the seasons. During periods of active growth when photosynthetic activity is high, transport is often predominantly basipetal from foliage to roots. However, in deciduous species coming out of dormancy in early spring, transport may be predominantly acropetal as carbohydrate stored in the roots and trunks is mobilized to facilitate bud burst and leaf production. Translocation and phloem transport is symplastic movement of substances through the interconnected cytoplasm of interconnected living cells (Salisbury and Ross, 1992).

The ratio of the amount of phloem tissue to xylem tissue may be as high as 1 to 4, but is more usually about 1 to 6 and in many tree species is closer to 1 to 10 (Fahn, 1975). The velocity of the movement of solutes through the phloem over long distances can be quite rapid, varying from about 100 – 1000 mm per hour (Fahn 1975, Salisbury and Ross 1992; Atwell et al, 1999) with sieve tube cells emptying between 3 to 10 times per second (Fahn, 1975; Salisbury and Ross 1992; Atwell et al, 1999). Interruption to phloem transport by ring-barking and girdling would lead to rapid depletion of carbohydrates.

Table 1. Some natural and human causes of ring-barking and/or girdling

Human caused Ring-barking/Girdling	Naturally caused Ring-barking/Girdling
Agricultural killing of trees to clear paddocks	Grazing by animals, particularly horses
Foresters killing selected trees to thin stands	Stripping of bark by birds, such as cockatoos
Orchardists killing branches and controlling vegetative growth	Tunneling insects under the bark grazing on bark and cambial tissues to excess
Orchardists controlling fruit, yield, size and sugar content	Fungal diseases, such as collar rot
Placement of wires and nylon ropes around tree trunks and branches	Circling or girdling roots which can occur naturally, as well as from poor nursery propagation
Unintended damage from use of poor staking	Trunk damage from rocks, such as in trees germinating in crevices
Unintended damage from mowers and whippersnippers	Bark eating rodents
Unintended root girdling of the stem by roots due to poor propagation and/or planting techniques	
Accidental damage from motor vehicle impact	
Unintended damage from construction works	
Deliberate vandalism to trunk and branches	
Unintended trunk damage from pavements and hard surfaces	

The most immediate effect of these changes in transport is that hormones synthesised in the roots no longer travel above the zone of ring-barking and those produced by the foliage no longer reach the roots below. Often it is the interaction of different hormones at appropriate concentrations that affect the physiological responses and so root and shoot growth and development can be impacted. Over the longer term, however, it is the failure of photosynthate to reach the root system that has significant consequences that can kill the tree.

For some time after damage, growth and both branch and trunk incremental increases above the zone of ring-barking continue. Indeed foliage condition may improve and incremental growth rates increase as all of the carbohydrate produced by the foliage remains in the region of the trunk and canopy, as none is able to reach the root system. So the trunk above the ring-barked zone increases in girth and there is often a noticeable swelling above the ring-barking cut. Growth below the cut slows and eventually ceases and so an obvious difference develops in the trunk diameters above and below the ring-barking zone (Figure 1).

Immediately after ring-barking, most trees have sufficient carbohydrate reserves in the root cells to maintain an active cell metabolism and root growth. However, as time passes these reserves are gradually consumed, at which point root growth ceases and root cells begin to starve from lack of carbohydrate (Salisbury & Ross, 1992; Taiz and Zeiger, 2002). Water and nutrient uptake is then affected and the tree starts to shed foliage, foliage becomes chlorotic and finally, and often quite suddenly, the tree wilts and the plant above the zone of ring-barking dies, which may result in the death of the whole plant.

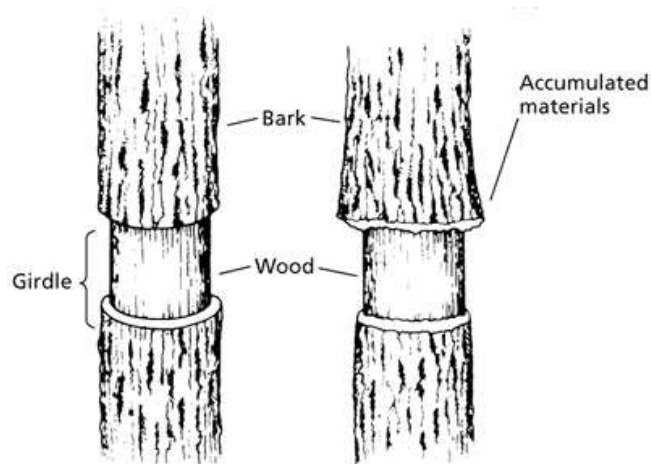


Figure 1. Swelling above the cut on a ring-barked stem (Taiz and Zeiger, 2002)

For a large tree with substantial carbohydrate reserves and a good root system, this process may take place over a period of between 2 to 5 years. However, if there are additional environmental stresses such as drought, flooding or waterlogging the decline of the tree will be accelerated.

Girdling affecting xylem and phloem tissues and transport

When girdling occurs, both translocation through phloem and transpiration through the xylem tissues are affected. However, the effect on transpiration is immediate as water supply to the trunk and canopy above the zone of girdling is cut and so on a warm windy day, wilting can begin almost immediately (McLuckie and McKee, 1954; Kramer & Kozlowski, 1960; Taiz and Zeiger, 2002). For most of the canopy and trunk above the girdling cut, permanent wilting will be reached within 24-48 hours depending on the size of the tree and environmental conditions. This girdling is a very effective method of killing plant tissues above the cut and the effects are almost immediate.

In contrast to transport through phloem tissue, transport of water and nutrients can be both symplastic and apoplastic (Figure 2). The latter is the movement of water and dissolved substances through the non-living cell walls and intercellular spaces of the plant. It is often forgotten that movement through the cell walls and intercellular spaces on a large tree can be quite significant and it is this movement and the properties of water, that go a long way to explaining why tissues immediately above cuts made in the trunk may not dry out or die. This may also explain why trees with major cuts though their trunks remain hydrated, healthy and growing.

It should also be noted that some species have anomalous secondary growth (Esau 1965). Such growth may result in some trees having alternating rings of cambium, xylem and phloem while others have lobes of xylem alternating with phloem. For some species from some dicotyledonous plant families, including *Myrtaceae*, phloem may occur inside as well as outside the xylem (Fahn, 1974). This intraxylary phloem may make it difficult to effectively ring-bark or girdle trees that exhibit this unusual structure and may explain why some juvenile trees which appear to be ring-barked or girdled remain unaffected.

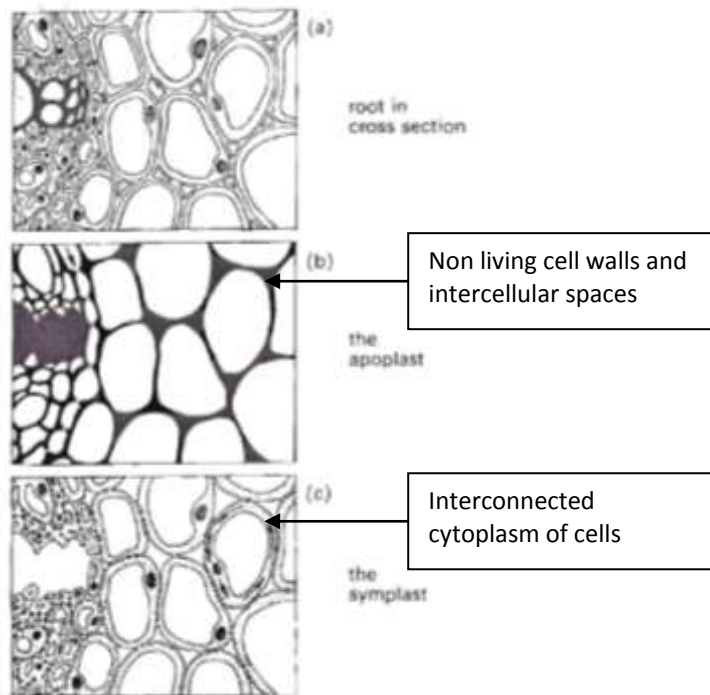


Figure 2. Symplastic and apoplastic pathways of plant transport (Salisbury and Ross, 1992)

The importance of the ring-barking and girdling cut and tree responses:

The physiological response of a tree is also influenced by the depth, width and location of the cuts made to affect the ring-barking and girdling (Figure 3). If the width of the cut made is quite narrow then the tree may be able to grow over the cut by producing callus, which can differentiate into woundwood within weeks to a few months (Neely, 1988; Goren et al, 2004). Trees are well-known to have simply grown over wire and other narrow obstructions, and ring-barking bands narrower than 100-150mm have been known to be grown over by large mature trees with substantial girths and carbohydrate reserves. Deliberate attempts to kill trees by ignorant or lazy vandals have also been thwarted when the cut narrow band (as narrow as 20-25mm) was simply grown over within a few months and the tree remained healthy and vigorous.



Figure 3. The width and depth of the cut affects the tree's response to ring-barking

Ring-barking and girdling are large wounds and the usual tree response is to produce callus from the cambium at the margins surrounding the damage. Callus production is greatest in vigorous trees but is affected by tree size, species and season (Neely, 1988). Spring, particularly early in the growing season, is typified by very fast responses to wounding and very rapid callus production, which can cover the damaged surface. Callus and

woundwood that predominantly develops from xylem ray cells grow best when xylem tissue growth is most active (Harris et al, 2004).

If the tree has dormant buds, such as axillary or epicormic buds, below the cut made to ring-bark or girdle a tree, these may be stimulated to develop by the cessation of basipetal transport of auxins from the canopy. The auxins will be the primary hormone involved in the inhibition of these dormant buds. If these buds develop with sufficient speed and grow to be large enough, they may send photosynthate down to the root system which will continue to absorb and supply water and nutrients to the canopy. Similarly trees that have adventitious buds or roots may provide a system for circumventing the damage from ring-barking and girdling.

In these situations it is possible that the parts of the tree above and below the ring-barking cut may survive for very long periods of time and even many decades. Species that can produce adventitious roots, such as species propagated by layering, for example *Ficus* species or some river red gums, *E. camaldulensis*, are capable of surviving for decades, and possibly centuries under such circumstances. However, the part above the cut usually eventually becomes stressed from environmental factors, such as drought or waterlogging, or the impact of insect grazing.

Another important aspect of ring-barking and girdling is the extent to which it occurs. There may be full or partial ring-barking and girdling of the trunk or major branches and stems. The effects of full ring-barking and girdling are clear, but a question arises as to how much of the vascular tissue needs to be intact for a tree to survive and recover over the longer term. Unfortunately there is little published information on this matter (Priestley, 2004) but it is known that there is variability in response for different species of trees, which is also influenced by season and environmental conditions (Neely, 1988).

Trees have certainly survived ring-barking and girdling to 50% of their trunk vascular tissues (Homes, 1984) and young trees of *Eucalyptus camaldulensis*, *Platanus orientalis* and *Acacia melanoxylon* survived and recovered from 60, 75, 90 and even 100% damage (Priestley 2004). Furthermore, foresters trying to kill weedy woody species, such as beech, poplar and some maple species by girdling have reported how difficult it can be (Glass, 2011; Kilroy and Windell, 1999). For the white poplar, *Populus alba*, which has the capacity to prolifically sucker, it has been reported that new bark can develop over the cuts in a matter of weeks (Glass, 2011).

The author's observations have been that as little as 10% vascular connection can be enough for trees to remain healthy, if the tree is growing in ideal situations and is kept free of pests and diseases (Moore, 2011). Deliberate attempts to kill the historic Separation Tree in the Royal Botanic Gardens Melbourne in 2010 by ring-barking or girdling reported that a band of bark between 400 and 900mm wide was removed from 80% of the circumference (Fagg, 2012; Moore, 2011). With 20% vascular connection, the tree remains in full foliage, healthy and both callus and woundwood have been produced expanding the vascular connection. The woundwood differentiates into xylem and phloem tissues and new vascular cambium is also developed (Harris et al, 2004).

Other effects of Ring-barking and Girdling

One of the reported consequences of ring-barking has been an increase in fruiting and flowering, which is often attributed to the retention of and higher levels of carbohydrate in the canopy of the tree (Kramer and Kozlowski, 1960), as well as a survival response at times of extreme stress (Taiz and Zeiger, 2002). This response is the basis of the use of horticultural girdling and ring-barking, which usually leaves between 10-20% of the vascular connection intact (Goren et al, 2004). However, there are little, if any data published on plant longevity after ring-barking or girdling.

In research on the effects of ring-barking and girdling young trees of *Eucalyptus camaldulensis* and *Platanus orientalis* trees were girdled and *Acacia melanoxylon*, trees were ring-barked for 60, 75, 90 and 100% of their girth (Priestley, 2004) using the definitions of ring-barking and girdling presented earlier. While the depths of cut were different, the results were not as there were no apparent differences between trees in their responses regardless of whether they had been ring-barked or girdled.

Interestingly, whole tree or above cut deaths only occurred in the 100% treatment. All specimens survived even 90% ring-barking or girdling, probably because the experiment was conducted over a 13 week period which was not long enough for plants to die and because the trees were juvenile and vigorous, they simply grew over the cuts that were made to the trunks. Callus tissue is produced by repeated divisions of the most recent derivatives from the cambium with the majority of callus (parenchyma) cells originating from cells

destined to form xylem rays (Neely, 1988). Young trees would contain a lot of such tissue. However, a number of interesting other effects emerged (Priestley, 2004):

- For *P. orientalis*, the more severe the treatment the slower the bud burst in spring and the less dense the canopy that subsequently developed (a greater response as you go from 60-100%). Later in the season the numbers of fruits produced by the 90 and 100% treatments were significantly lower averaging 6.25 and 4.00 per tree respectively compared to 14.25 for untreated controls.
- For *P. orientalis*, the more severe the treatment the greater the number of branches that were shed from these young tree (again, a greater response as you go from 60-100%).
- For *E camaldulensis*, the undamaged controls showed an average increase in height of about 62mm, while none of the girdled treatments average over 30mm and most were considerably less.
- For *E camaldulensis*, the level of Psyllid infection at the end of the experiment was between 60 and 90% for ring-barked specimens compared with an infection rate of 12.5% in undamaged controls.
- For *A melanoxylon*, there was an effect for infection with leaf blight but in the reverse direction. The blight affected control plants but was much reduced for the most severely ring-barked treatments.

What these data reveal is that even incomplete ring-barking or girdling can affect the growth and development of injured trees as well as their responses to pest and diseases.

Arboricultural treatments for Ring-barking and Girdling

A number of arboricultural treatments for ring-barking and girdling have been suggested, including:

- When bark is removed from a tree accidentally or by vandalism, the bark should be replaced in position immediately as natural grafting and callus growth can take place so that growing over occurs very quickly. This process can be described as bark patch grafting. The key to success is speed, as the bark that has been detached cannot be allowed to dry out nor can the damaged edges of the bark remaining on the tree dry. The work of Chandler (2009) showed that keeping eucalypt woody tissues moist facilitated successful callus growth and grafting success in *Eucalyptus leucoxylon*. Care must also be taken to replace the bark at the right orientation so that, for example, the part facing upward remains in that orientation and that there is as much contact as possible between the replaced patches of bark and the bark on the tree (McGarry, 2001). The bark can be held in place by any biodegradable material, but any fastening will suffice given the size and seriousness of the wound. Success may also be affected for some species by season, with better rates of patch grafts occurring in spring and autumn for eucalypts than in winter or mid-summer (McGarry, 2001).
- Bridge grafting is a well-known horticultural technique that has a long history of use in repairing damaged orchard trees (Hartmann and Kester, 1975; Harris et al., 2004) but it has also been used to repair damaged ornamental trees of historic, heritage, cultural, landscape and horticulture significance which warrant the expenditure. The technique uses bark tissue from the same specimen, a clone, or the same species, which is inserted into the remaining healthy bark of a ring-barked or girdled tree. The objective of bridge grafting, as the name suggests, is to provide channels of connection of both xylem and phloem tissue that allow transport basipetally and acropetally once more (Figure 4). Success relies on healthy cambium producing callus at both ends of the grafted bark and the rate of success can be influenced by species and seasonal factors. Bridge grafting requires skill and is quite expensive to undertake and so it is usually only contemplated for outstanding and significant trees. On a large tree, a number of grafts, up to 10 or more may be inserted, and the aesthetics of the outcome are sometimes questioned by arborists and the general public.

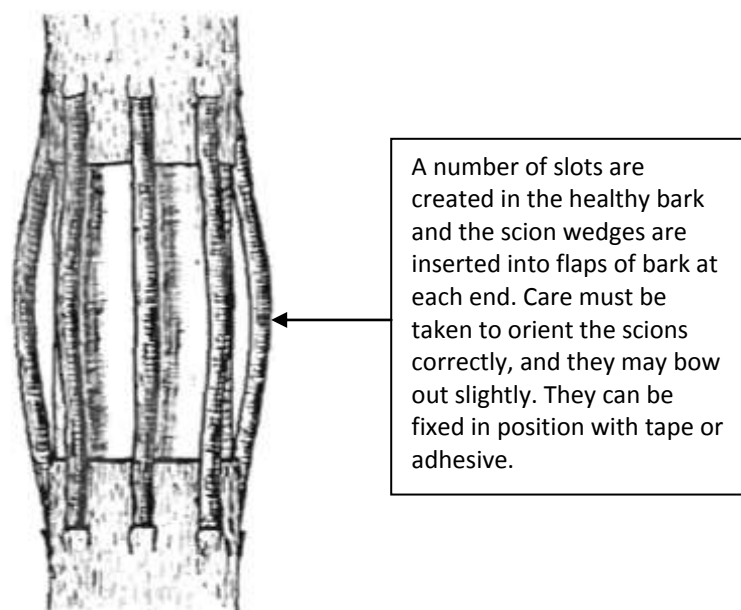


Figure 4. Bridge grafting of a ring-barked trunk (modified from Hartmann and Kester, 1975)

- Approach grafting and inarching are other well-known horticultural techniques used in repairing damaged orchard and valuable ornamental trees (Hartmann and Kester, 1975; Harris et al., 2004). They differ in that for inarching, the top of the new rootstock plant does not extend above the point of the graft union. Inarching is considered to be a form of 'repair grafting'. Both techniques involve growing young seedlings that are progeny of the damaged plant, clones or at least of the same species as the damaged plant around the base of the damaged tree. The young trees should be of a reasonable size (1-2m in height with a stem diameter of 20-25mm if possible) and the trunk or one of the larger branches is then inserted into the healthy cambium of the damaged tree above the upper cut of the ring-barked or girdled region. The objective of approach grafting is to provide water and nutrients to the part of the damage tree above the zone of ring-barking or girdling, but it does not provide for transport downwards to the original root system. However, if successful and given enough time the young tree root systems develop as the original system declines and in some cases natural root grafting between tree and seedling may occur (Tarroux and DesRochers, 2011). This technique is relevant when water is likely to be a limiting factor in the survival of a damaged tree and there is a significant risk of imminent wilting. Once more, approach grafting requires skill and is quite expensive to undertake. On a large tree a number of grafts, up to 6-8, or more grafts may be inserted, and the aesthetics of the outcome are sometimes questioned as there are a number of smaller trees growing around the trunk of the specimen.
- Another aspect of post-damage management that an arborist can undertake is to minimize the risks from environmental stresses. For the most part this will involve making sure that water and nutrients are not limiting and that there is no risk of waterlogging to the already stressed root system. Good subsurface irrigation and drainage and proper mulching around the drip line would be useful practices. Post-damage control of pests and diseases is also wise (Priestley, 2004). Even partial ring-barking and girdling of trunks or larger branches exposes plants to significant stress which may leave them vulnerable to pest and disease attack. For example, the attack on *E. camauldensis* by the psyllid, white lace lerp (*Cardiaspina albitextura*) was confined to trees that had been ring-barked or girdled and not to undamaged control trees that were largely unaffected (Priestley, 2004). Psyllids are attracted to high nutrient levels in foliage and population numbers increase rapidly in these conditions (Collett, 2001) which is consistent with ring-barking and girdling causing an increase in sugar and carbohydrate accumulation above the zone of damage (Kramer & Kozlowski, 1960). It is possible that these conditions might also suit some fungal pathogens.
- Injections of sucrose into the soil have been reported to significantly improve fine root growth of established trees with responses dependent on species and the sugar concentrations applied (Percival et al, 2004). It is unclear whether the response is due to the direct uptake of the sugar by

the roots or to enhanced mycorrhizal growth, which would also benefit the tree. The timing of such applications is also critical. It should not be too early after damage as the roots, under normal circumstances, should have sufficient carbohydrate reserves, but could be applied when carbohydrate resources are in danger of depletion. Measurement of carbohydrate concentration in root tissue could inform the timing of application. Care must also be undertaken to ensure that the injected sugar does not benefit non-target organisms.

Conclusion

Depending on the tree and the conditions that it is growing under, ring-barking may not mean the death of a tree, but little can be done if a tree is effectively girdled severing the active xylem tissue. Arboricultural treatments that respond rapidly (within hours) to the removal of bark and which provide ideal growing conditions for the tree enhance the chances of recovery from ring-barking. Treatments may involve irrigation, mulching, prevention of compaction and waterlogging and effective pest and disease control.

Depending on the species, environmental conditions and the time of year, re-affixing displaced bark (bark or patch grafting) can be successful if it is done within hours of removal and the tissues, both intact and displaced, have not dried out. If successful, callus production can be very rapid and growing over can occur within months. If the tissues dry or cannot be replaced other interventions such as bridge or approach grafting may be contemplated, but they can affect the aesthetic value of the specimen.

It should also be understood that healthy vigorous trees that appear to have been fully ring-barked or girdled, on closer and detailed inspection may prove to have only been partially girdled or ring-barked. Such trees may survive with as little as 10-20% vascular connection or less if they are young and healthy. Under these circumstances, the “do nothing to the tree” option may be an appropriate response provided that good arboricultural management practices are implemented subsequent to the injury.

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