Final Report

Reconnaissance and Recommendations for Mistletoe Management in Macadamia Orchards

Project leader:

Prof David Watson

Delivery partner:

Charles Sturt University

Project code:

MC18001

Project:

Reconnaissance and Recommendations for Mistletoe Management in Macadamia Orchards – MC18001

Disclaimer:

Funding statement:

This project has been funded by Hort Innovation, using the macadamia research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978 0 7341 4475 1

Published and distributed by: Hort Innovation

Level 8
1 Chifley Square
Sydney NSW 2000

Telephone: (02) 8295 2300

www.horticulture.com.au

Contents

SUMMARY

Mistletoe is an emerging pest in the Macadamia industry, affecting tree growth, nut yield and interfering with orchard operations, and is regarded as a major issue for growers in the Northern Rivers region of New South Wales and in the Gympie, Bundaberg and Rockhampton regions of Queensland.

- 92 species of mistletoe occur in Australia, with five (*Amyema congener*, *Benthamina alyxifolia*, *Muellerina celastroides*, *Dendropthoe glabrescens* and *D. vitellina*, all in the Loranthaceae) infecting Macadamia trees.
- The *Dendrophthoe* species are the most problematic in terms of abundance and growth habit, with external runners and multiple attachment points allowing the mistletoe plant to move up the canopy, shading the tree and hampering mechanical removal.
- As with other mistletoes, *Dendrophthoe* is dispersed by birds (primarily Mistletoebirds, but also Brown Honeyeaters and other frugivorous songbirds). Once the fruit is digested, the sticky surface of defecated seeds adheres to the perch or lower branches.

The biology and life history of mistletoe makes it an especially problematic pest for Macadamia growers. Current approaches to orchard establishment and management increase the susceptibility of macadamias to mistletoe infection.

- Mistletoe seeds lack a seed coat and are photosynthetically active, requiring deposition in a well-lit environment to germinate and establish. Mistletoes are more likely to establish on trees with access to more water and nutrients and with a well-lit canopy
- Those macadamia varieties with more open canopies (including 816, 203, A16, A4, A38, 344) are more susceptible to mistletoe infection, compared to other varieties (including 661, 846, 741) that have a more contiguous canopy and more upright growth habit
- Canopy management that trims the crown and removes inner branches to increase light penetration and greater nut-set yields inadvertently increases the susceptibility of macadamia trees to mistletoe infection, seeds more likely to germinate and establish

The most effective mistletoe control in Macadamia orchards is to apply integrated pest management principles: monitor regularly to detect infections and reinfections, remove existing mistletoes, adjust canopy management to reduce susceptibility and decrease likelihood of reinfection, and work with natural enemies to reduce mistletoe vigour.

- Monitoring orchards to evaluate where mistletoe occurs and detect any change in infection severity and extent is fundamental. Systematic searches are useful, but other options may be more cost effective; e.g., involving all personnel working in orchards to flag all mistletoes they encounter
- Mechanical removal (by pruning off infected branches) is the most effective control measure and needs to be conducted regularly, at least twice per year.
- Incorporating mistletoe control into routine grower management systems and coordinating control measures across adjacent properties is the most effective way to minimize impacts of mistletoe on tree health and decrease rates of reinfection

Further research is needed to establish best-practice removal methods, estimate the effect of mistletoe infection on macadamia tree growth and yield and explore cost-effective control strategies that align with existing orchard operations

- Effective methods for detecting mistletoe is a priority, both to identify those areas requiring management and also for evaluating efficacy and optimal frequency of existing management practices. Drone-borne near infra-red imaging systems offer great potential to detect mistletoes

and estimate infection severity and extent.

- Comparisons of infection rates of different varieties and/or canopy management strategies of Macadamias is a priority, best replicated in all growing regions where different mistletoe species occur and growing conditions vary.
- Chemical control of mistletoe with herbicides and growth regulators has been trialed and used on other plants with mixed effectiveness. Trials are needed to determine whether such chemicals have a role in mistletoe management on macadamias. Chemicals showing potential as effective and safe for mistletoe control should be considered for trials that can lead to a permit for use as part of integrated pest management.
- Bird deterrents currently in use to deter parrots from Macadamia orchards may deter mistletoe dispersers, but would need to be conducted at orchard scales to be effective.
- Mistletoes are favoured food plants of many animals, and harbor beneficial insects that may control mistletoe growth, suppress macadamia pests or increase pollination of macadamias
- Raising awareness with all relevant stakeholder groups regarding the impact of mistletoe on macadamias will facilitate targeted research to address knowledge gaps and develop best-practice control protocols.

Keywords

Macadamia, Mistletoe, Parasitic plant, Loranthaceae, *Dendrophthoe*, Integrated Pest Management, Canopy management, Beneficial insects

INTRODUCTION

Macadamias are a rapidly growing horticultural industry in Australia. Unlike more established crops where considerable investment in research over many decades has informed best-practice guidelines for orchard management, many aspects of growing, maintaining and harvesting macadamias are unclear, and the subject of ongoing trials. As the industry has grown and orchards have expanded, numerous pests have emerged. As a native plant with some of the largest growing areas overlapping with its native distributional range, macadamias host a diverse suite of ecological associates, including both pest and beneficial insects, birds and mammals that eat nuts and young branches, fungi and parasitic plants. Mistletoes have emerged as a pest in the Australian macadamia industry, with many unanswered questions regarding their impacts on tree health and nut yield and no established guidelines on the most effective control measures.

In December 2018, Ms Melinda Cook and I visited macadamia orchards in both the Gympie and Bundaberg regions. We toured orchards with varying levels of mistletoe infection and discussed mistletoe management with property owners, orchard managers and on-ground staff (Fig. 1). I also led a growers' workshop, summarizing current knowledge about mistletoe biology and ecology, and facilitated knowledge sharing between growers on all aspects of mistletoe impacts and management. In this report, I summarize interim recommendations for mistletoe management emerging from these discussions and on-ground surveys, integrating this information with relevant research on mistletoe from other systems. I summarize best practice recommendations for mistletoe control, emphasizing the application of core integrated pest management principles to minimise impacts on orchard operations and profitability. Finally, I present priorities for further research to address strategic knowledge gaps.

Fig. 1. Macadamia growers are increasingly concerned about mistletoe, and how best to control these parasitic plants in their orchards. Photograph by David M. Watson

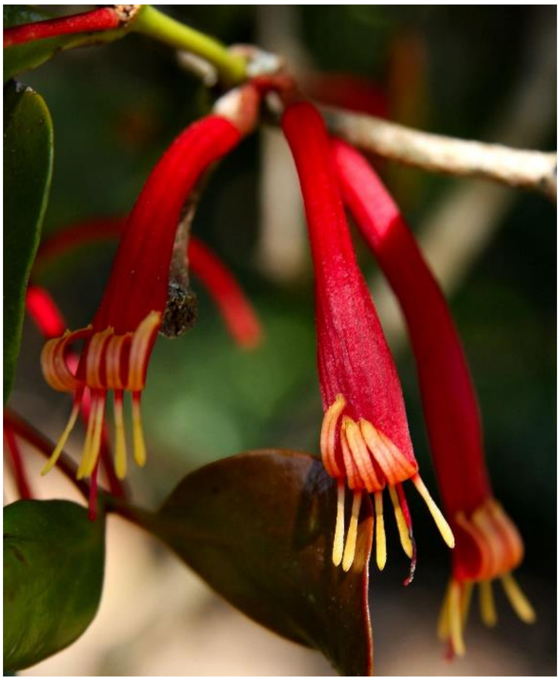
MISTLETOE IN MACADAMIA ORCHARDS

As the only native Australian plant grown in commercial horticulture, *Macadamia integrifolia* (hereafter, macadamia) has posed a unique set of challenges for growers. As well as determining which varieties are well-matched to their growing conditions and how best to maximise yields, growers constantly deal with a wide range of native insects, fungi, birds and other ecological associates that have coevolved with the tree. This is especially the case in the growing regions of northern New South Wales and southern Queensland where all four Macadamia species still occur in the wild (Mast et al. 2008).

One set of ecological associates that has emerged as an issue for commercial macadamia growers is mistletoe (O'Hare et al. 2004). Mistletoes are parasitic plants, attaching to woody hosts above ground via a specialized organ called a haustorium. This functional group of approximately 1,500 described species comprises five families of flowering plants in the Santalales, of which three families occur in Australia: Loranthaceae, Viscaceae and Amphorogynaceae (Watson 2011). The Australian mistletoe flora comprises 92 described species, with many plant genera acting as principal hosts for particular mistletoe species (Watson 2011). Thus, *Acacia, Alphitonia, Auracaria, Brachychiton, Callitris, Casuarina, Flindersia, Hakea, Melaleuca and Terminalia* species all act as principal hosts for one or more mistletoe species, interactions that have reciprocally sculpted traits in both host and parasite for millions of years. Members of the Proteaceae frequently host mistletoes, with species depending on Grevilleas and Hakeas (*Amyema gibberula*) and Banksias (*Muellerina celastroides*) as principal hosts (Downey 1998; Watson 2011).

Species

Macadamias have been recorded acting as hosts for *Benthamina alyxifolia* (Figs 2, 3), *Mullerina celastroides* (Figs 4, 5), *Amyema congener* (Figs 6, 7), *Dendrophthoe glabrescens* (Figs 8, 9), and *Dendrophthoe vitellina* (Figs 10, 11; Downey 1998; Watson 2011; Moss and Kendall 2016). Based on orchard surveys and discussions with growers, the issues associated with mistletoe in Macadamia orchards relate primarily to *B. alyxifolia* (below) and the two *Dendrophthoe* species, characterized by orange flowers and upright, flask-shaped fruit.



Figs. 2, 3. Shiny-leaved Mistetoe *Benthamina alyxifolia*, a monotypic genus endemic to rainforests of eastern Australia, and the main species affecting Macadamia growers in northern New South Wales. (photographs by Black Diamond)


Figs 4, 5. Coast Mistletoe *Muellerina celastroides*, a slow-growing species found primarily on Banksia species, but occasionally found on Macadamias. Photograph by Roger Fryer and Jill Newland (left) and David M Watson (right).


Figs 6, 7. Erect Mistletoe *Amyema congener*, a shrubby species that forms a simple attachment to hosts, a frequent parasite of macadamias in the Gympie region. Photograph by Murray Fagg (left) and David M Watson (right)


Figs 8, 9. Long-flowered mistletoe *Dendrophthoe vitellina*, the most abundant mistletoe in Macadamia orchards in the Bundaberg region. (Photograph by Tony Rodd (left) and Melinda Cook (right).


Figs. 10, 11. Smooth mistletoe *Dendrophthoe glabrescens*, with flowers arranged around a central stalk. This is the dominant species infecting Macadamia orchards in the Rockhampton region. Photograph by Roger Fryer and Jill Newland (left) and Bill Higham (right).

Dispersal

As with all Australian mistletoes, the species infecting Macadamias have abundant fleshy fruits containing sticky seeds which are dispersed by birds. Mistletoebirds (figs 12, 13) are likely the most frequent mistletoe disperser, but Brown Honeyeaters (Fig. 14), Silvereyes, Figbirds, Common Koels and various honeyeaters and other fruit-eating birds also frequently consume mistletoe fruit as part of a broader diet and may act as seed dispersers (Reid 1989). Previous work demonstrated that Mistletoebirds preferentially feed in areas with dense mistletoe infections (Rawsthorne et al. 2012), so this specialist is the likely agent of intensifying and spreading existing infections, whereas these other species may be important in establishing new infection centres (Watson and Rawsthorne 2013).

The subtropical forests of eastern Australia are home to 23 species of mistletoe in the Loranthaceae (Watson 2011; Moss and Kendall 2016), with 14 species observed in preliminary surveys in remnant vegetation adjoining Macadamia orchards. Prior work on the tempo of mistletoe flowering and fruiting patterns has demonstrated these species exhibit complementary phenology, peak fruiting of co-occurring species staggered to maximise frugivore visitation and seed removal (Reid 1986; 1989). Thus, in the Macadamia growing regions of eastern Australia, ripe mistletoe fruit is available year-round, likely supporting resident populations of mistletoe-dispersing birds. Within orchards, *Dendrophthoe* plants exhibit extended phenology. Thus, while individual plants only flower and fruit once per year, peak fruiting of individual plants varies considerable, even within the same orchard, with ripe fruit available across multiple seasons.

Figs. 12, 13, 14. Male Mistletoebird *Dicaeum hirundinaceum* (left), Female Mistletoebird (centre) and a Brown Honeyeater *Lichmera indistincta*, (right), the two principal species dispersing mistletoe in Macadamia orchards. Photograph by Nevil Lazarus (left), Ian Montogomery (centre) and Aviceda (right).

Previous work on the movement ecology of Mistletoebirds has demonstrated that they occur in a wide range of habitat types, their movements and breeding activity determined primarily by mistletoe availability (Rawsthorne et al. 2012). As a mistletoe fruit specialist, they have a rapid gut passage rate, with an average gut retention time of 14 minutes (Richardson and Wooller 1988). Equivalent research has not been conducted on Brown Honeyeaters, but the ecologically similar Spiny-cheeked Honeyeater was found to have a gut passage rate of 30 to 60 minutes (Murphy et al. 1994; Rawsthorne et al. 2011). While seeds are primarily ingested along with the fruit, sticky seeds frequently adhere to their feathers, allowing occasional long distance dispersal. Experimental trials moving fruiting mistletoe plants into uninfected trees revealed that Mistletoebirds use both visual cues and spatial memory to locate fruiting mistletoes (Cook 2017). As well as the mistletoe itself, birds associate mistletoes with their principal host, searching through uninfected trees for mistletoes.

Mistletoe germination and establishment

Unlike most plants, mistletoe seeds lack a testa or seed coat (Kuijt 1969; Calder and Bernhardt 1983). Accordingly, once removed from the colourful fruit (Fig. 15), the seeds are prone to desiccation, defining a narrow window of viability within which germination can occur. Mistletoe seeds are green and photosynthetically active, and need to be deposited in a sufficiently well-lit microsite to allow them to photosynthesize the carbohydrates required for initial growth. Remaining viscin (sticky substance) on the surface of the seeds rehydrates in humid or damp environments, providing a water source for the developing plant. As the hypocotl (germinating stem) emerges from the seed and elongates (Fig. 16), penetration into the host vascular tissue is effected by hydrostatic pressure, the modified root embedding within the cambial layer of the host. Once the developing mistletoe is attached to the host vascular system, nutrient flow is initiated and cotyledons emerge (Watson 2011 and references therein).


Figs. 15, 16. Long-flowered Mistletoe fruit, contrasting against the green foliage of macadamias and readily detected by birds (left). Four mistletoe seeds deposited on an Acacia by a mistletoebird (right). Note the elongated hypocotl with a swollen distal end—this is the point of attachment from the haustorium develops. Photograph by Melinda Cook (left) and Dirk Spenneman (right).

Of the mistletoe species recorded on infected Macadamias, all except *Amyema congener* develop epicortical shoots—root-like runners emerging from the initial attachment point and growing along the infected branch (Fig. 17; Watson 2011). This allows multiple attachment points of the hemiparasite, enabling shoots avoid shading by the host (Fig. 18). If leaf-bearing shoots are removed (either by fire, herbivory or wind-shear, plants can resprout from any of these attachment points.


Figs. 17, 18. A young (left) and mature (right) smooth mistletoe plant growing on a Macadamia exhibiting epicortical runners. If leaf-bearing shoots are removed, the mistletoe can regenerate from any of these attachment points. Photographs by Melinda Cook.

Effects on trees

Although the direct and indirect effects of mistletoe infection on Macadamia trees have not been formally quantified, surveys of infected orchards in the Gympie and Bundaberg regions revealed a range of impacts, consistent with published work on other host-mistletoe combinations (Reid et al. 1995). Initial infection interrupts vascular flow of the host branch, water and dissolved nutrients diverted by the growing hemiparasites (Lamont 1985). This typically decreases the growth of the distal portion of the infected branch, the proximal portion of the branch enlarging and forming callous tissue around the developing haustorium. Initial impacts on infected hosts are analogous to a self-shaded branch, the branch receiving water and nutrients but not delivering photosynthate (Press et al. 1990).

If mistletoe growth is unchecked, mistletoe becomes a progressively greater component of the tree canopy, shading host foliage and diverting increasing fraction of vascular flow (Hawksworth 1983). For host trees receiving irrigation and fertilization, mistletoe infection will have little effect on water balance or nutrient status of the host tree (Ehleringer et al. 1986; Glatzel and Balasubramaniam 1987) but will impede access to light. This is especially the case for *Dendrophthoe* mistletoes, with the long leafy shoots forming a dense layer atop the host canopy. As the host tree grows, the epicortical runners establish new vascular connections, growing with the host and further shading the host canopy. This alters canopy architecture, heavily infected trees becoming top heavy and shaded branches dying off. Infected branches become lopsided (Fig. 19), and are more likely to be lost due to wind shear and after heavy rain. As birds visit the established mistletoe, more seeds are deposited, secondary infection occurs and the canopy becomes dominated by mistletoe foliage (Fig. 20; Aukema and Martínez del Rio 2002). Although not necessarily fatal, intensifying infections will lead to progressively diminished tree health, fewer flower-bearing branches and, ultimately less nuts.

Fig. 19. Macadamia tree with an established mistletoe infection. Note the sparse canopy, lopsided growth and dead branches. Photograph by David M Watson.

Fig. 20. A 14-year old macadamia tree with an established mistletoe infection emerging from the centre of the canopy. Infected branches were pruned off seven months earlier, but the mistletoes resprouted. Photograph by David M Watson.

Determinants of susceptibility to mistletoe infection

Although determinants of mistletoe occurrence has not been formally quantified, discussions with growers and field surveys of infected orchards highlighted that a suite of characteristics at the tree, block and property scale likely contributed to observed infection patterns. By integrating these findings with experimental and descriptive work on other mistletoe / host systems (Carnegie et al. 2009), qualitative inferences can be made on those factors most likely to affect susceptibility to infection. Validating these inferences with comparisons of infected and uninfected trees at multiple scales is a key priority for further research.

Variety

Many varieties of macadamias are grown commercially; variety selection at individual orchards is typically based on overall growth habit, cross-pollination requirements, availability of nursery stock and, above all, nut size and yield. Some varieties are consistently more susceptible to mistletoe infection—in several properties visited, adjacent blocks of different varieties but otherwise comparable in age and management regime had substantially different levels of mistletoe infection. Specifically, growers reported that 816, 203, A16, A4, A38 and 344 varieties were much more susceptible to mistletoe infection than 661, 846 and 741.

Establishing the mechanistic basis of varietal differences in susceptibility to mistletoes is a priority, with several noteworthy characteristics arising during grower discussions. Rather than necessitating experimental inoculations, comparing infection rates and measuring candidate traits for selected varieties would distinguish those traits most likely to confer resistance to mistletoe infection. Thus, many of the A-series varieties have lighter foliage, sparser canopies and more open crowns (Fig. 21) , whereas the older Hawaiian varieties (including 661, 846 and 741) are comparatively more upright with more continuous canopies and closed crowns (Fig. 22). Some growers report anatomical differences among varieties, with 816 having rougher bark and 846 having thicker bark and cambium layers.


Figs. 21, 22. Adjacent rows of macadamias, A16 (left) and variety 846 (right) at Oakdale. Note the consistently more open crowns of A16 trees and the more continuous denser canopies of 846 trees, most obvious in the shadows between tree rows. Photographs by David M Watson.

Water status

Research on other host-mistletoe systems has demonstrated that trees with more reliable access to water are more likely to support mistletoes to maturity (Norton and Stafford Smith 1999). As with other parasitic plants, mistletoes have limited control over their water status and are disproportionately sensitive to water stress in their host plants (Ehleringer et al. 1986). Research on horticultural crops elsewhere, including Citrus and Guava trees in Sudan, Citrus and Cocoa trees in Ghana have found high rates of mistletoe infection in irrigated orchards, with periodic pauses to regular irrigation suggested as one way to manage severe mistletoe infections by effecting water stress in infected trees (Sidahmed 1984; Appiah 1997; Zaroug et al. 2009).

Nutrient status

As green plants, mistletoes photosynthesize their own carbohydrates, but lack their own root system and rely exclusively on their host plant for all their nutrient needs (Glatzel and Balasubramaniam 1987). Research on other host-mistletoe systems has demonstrated a clear preference for hosts with access to more nutrients (reviewed by Watson 2009), favoring leguminous species and those individual trees growing in more fertile microsites (e.g., atop old termite mounds). As well as Nitrogen, this host preference relates specifically to Phosphorous. Although there is no published work on the effect of fertilizer application on susceptibility to mistletoe infection, comparing infection rates in orchards receiving different fertilizer regimes would reveal any mechanistic link between Phosphorous application and mistletoe growth or initial establishment.

Canopy structure

With their dense, evergreen foliage, Macadamias typically form a continuous canopy with the branches inside the crown effectively shaded. Current grower management systems remove inner branches to open up the crown, aiming to increase light levels throughout the tree to promote fruit set and increase yield (Fig. 23). While pruning may boost yields, in orchards with existing mistletoe infections, mistletoe seeds are far more likely to germinate and establish in trees with more open crowns.

Fig. 23. Macadamia orchard where trees have been pruned to increase light infiltration. Mistletoe seeds landing in these open canopies are far more likely to establish than in more continuous, darker crowns. Photograph by Melinda Cook.

Tree location

Trees growing at the ends of rows are consistently more susceptible to mistletoe infection (Fig. 24). In addition to being less shaded, work on bird foraging behavior in other host-mistletoe systems indicates that these trees are likely to be visited more frequently by birds, receiving more mistletoe seeds. In contrast, those rows adjoining native vegetation or beside planted shelterbelts (both of which are frequently infected with mistletoe) are not necessarily more susceptible to infection. It is useful to consider tree placement within a row and orchard with respect to monitoring effort.

Established macadamia orchards vary considerably in planting density in terms of both spacing along rows and distance between rows. Comparing proportions of trees infected with mistletoe at different tree spacing will clarify the influence of tree density on susceptibility to mistletoe and discern any thresholds in overall canopy closure that may affect bird visitation, mistletoe germination or both.

Fig 24. Trees on row ends are more likely to become infected with mistletoe than trees in the interior of blocks, a pattern that likely reflects differences in tree rows as well as foraging behavior of birds. Photograph by Melinda Cook.

Natural enemies of mistletoe

With their high water content, enriched foliage, abundant nectar and nutritious fleshy fruit, mistletoes attract a range of animal consumers, many of which help regulate mistletoe numbers in native habitats. In terms of herbivores, two animal groups predominate: mammals and insects. Arboreal folivores including Common Brushtail and Common Ringtail Possum favour mistletoe foliage, with experimental work on captive animals and radio-tracking free ranging animals demonstrating consistently high preference for mistletoes mediated by high water content, high concentration of cations and high digestibility (Choate et al. 1987; Canyon and Hill 1997; Petrovic 2014). As well as arboreal marsupials, cattle, sheep, donkeys, goats, horses, camels and several deer species all browse preferentially on mistletoe where available (Watson 2001). Most of the research done on mistletoe consumption by mammals in Australia relates to mistletoes on Eucalyptus hosts, and it is unclear whether herbivores show similar preference for mistletoes on hosts in the Proteaceae (including Macadamias).

There have been two studies of the insect fauna of Australian mistletoes (Anderson and Braby 2009; Burns et al. 2011), and several findings are noteworthy. Firstly, the insects found on mistletoe foliage are not a subset of those found elsewhere in the crown of the host. Rather, mistletoe plants support their own distinctive assemblage of insects (Fig. 25). Secondly, many of the insects found in mistletoes occur nowhere else—they are mistletoe specialists. The best studied group is butterflies, with 27 species known to depend on mistletoe as food plants for their larvae. Two families predominate—the Jezebels (Pieridae) and the Azures (Lycaenidae)—and, upon hatching the larvae feed exclusively on mistletoes on a wide range of hosts, often defoliating the entire plant (Braby 2006; Moss and Kendall 2016) but leaving the host tree untouched. Flowering mistletoe are also important food plants for adult butterflies and moths, especially in temperate and arid woodlands when mistletoes are one of the more reliable sources of nectar (Hawkins et al. 2018). Many other insects are associated with mistletoes: grasshoppers, thrips, lerps and beetles all contain mistletoe specialist species, living out their entire lives within these parasitic plants (Watson 2004).

Mistletoes are frequently colonized by fungi (Fig. 26; Shamoun et al. 2003), but little research has been conducted on these interactions in Australia (Beilharz 1997), and it is unclear whether these organisms are specific to mistletoes or host pathogens that affect the entire canopy. The final set of ecological associates that may regulate mistletoe numbers are other mistletoes, specifically epiparasitic species that preferentially infect other mistletoes (Bernhardt 1984). During surveys of macadamia orchards and adjacent vegetation, two species were commonly encountered: Square-stemmed mistletoe *Viscum articulatum* (Fig. 27) and Golden Mistletoe *Notothixos subaureus* (Fig. 28). Both were frequently seen infecting established *Dendrophthoe* plants but, based on previous work on epiparasitic mistletoes (Bernhardt 1984; Wiens and Calvin 1987 see also Glatzel and Balasubramaniam 1987), it is doubtful that either have a significant deleterious effects on their individual host.


Figs. 25, 26. Insect eggs (identity unknown) found on a smooth mistletoe in a Macadamia Orchard (left). A gall-forming fungus, emerging from a long-flowered mistletoe growing in native vegetation adjacent to a macadamia orchard (right). Photographs by Melinda Cook.

Figs. 27, 28. Two epiparasitic mistletoes that rely on other mistletoes as principal hosts, both of which occur on *Dendropthoe* mistletoes in Macadamias. Square-stemmed mistletoe *Viscum articulatum* (left) has pendulous stems and pearly white fruit; Golden Mistletoe *Notothixos subaureus* has distinctive yellow bloom on young leaves. Photos by Roger Fryler and Jill Newland (left) and Murray Fagg (right).

MISTLETOE CONTROL MEASURES

During the grower workshop, conversations with Macadamia growers revealed numerous trials of control methods to remove mistletoe and prevent reinfection, with varying success. Although these trials are characteristically small-scale, un-replicated comparisons conducted on single properties, the qualitative results are an instructive primer to guide larger scale trials. By integrating lessons learned from these trials with findings from other crops affected by mistletoe (horticultural and forestry, both in Australia and elsewhere), those control measures with the greatest relevance to macadamia growers can be identified. Australian pecan growers and plantation foresters have also trialled various approaches to control mistletoe, with mechanical removal of mistletoes from infected trees found to be the most effective approach.

Early detection

Knowing where mistletoes occur within an orchard is critical to managing their effects. Currently, monitoring is typically conducted on either an ad hoc basis or as part of orchard-wide management regimes. Thus, mistletoes are either only dealt with once heavily infected trees become apparent, or the entire orchard is covered by teams on machinery, locating infected trees and removing all accessible mistletoes. Both of these are inefficient, either dealing with infections once they're already problematic or deploying teams of people to spend most of their time looking for mistletoes. Two alternative approaches should be trialled. Using a flagging system adopted by all orchard workers where any mistletoe detected during orchard operations is flagged, either physically or digitally, to be followed up by removal teams once a pre-determined threshold is reached at either the block or orchard scale. Alternatively, trial the use of a drone. Previous work in other systems has demonstrated that mistletoes are highly detectable from above. They are particularly easy to discern in tree canopies using near infra red imagery given differences in foliage albedo and significantly higher water content in mistletoe leaves that sclerophyllous hosts. Initial trials using drone-borne cameras to detect mistletoes in macadamia orchards has already been undertaken (Johansen et al. 2018), with further trials recommended. Time of day will likely be critical to enhancing detection, with mistletoes cooler than tree crowns in the early morning so will have a contrasting thermal signature (Maes et al. 2018).

Chemical

There are no chemical products permitted for use in macadamias to control mistletoe. Hence, the following information is for consideration as R&D as part of IPM for mistletoe. R&D on any chemical management of mistletoe would need to establish efficacy, rates, off-target effects, safety, residues and any trade implications.

Although the use of herbicides and growth regulators has successfully controlled mistletoe in ornamental and production horticulture and forestry (Greenham and Brown 1959; Reid et al. 2008 and references therein), outcomes vary considerably between systems, with no best-practice guidelines currently available for chemical control of mistletoes in any production system. The most successful approaches combine chemical control with mechanical pruning, a labour-intensive method that reduces the deleterious effects of mistletoe infection on host vigour and growth but is unable to prevent reinfection.

Various herbicides have been trialled using foliar spray, stem injection or direct application to mistletoes (Minko and Fagg 1989; Reid et al. 2008). Most of these trials have been conducted in the USA and Canada, focusing on dwarf mistletoes (Arceuthobium; Viscaceae) which can form systemic infections in coniferous hosts, fundamentally changing the growth habit of trees rendering them unsuitable for timber production (Hawksworth and Hohnson 1989). Although fundamentally different to the Macadamia / *Dendrophthoe* system (both host trees and mistletoes are from different families and exhibit many differences in plant anatomy and physiology) the lack of success in herbicide control despite millions of dollars of research investment over many decades is instructive. Limited trials have also been conducted in horticultural crops in the USA, with 2,4D successfully used in controlling mistletoe in pecans if trees were sprayed prior to bud break (Wood and Reily 2004), this timing critical to protect the host tree. Given the evergreen growth habit of macadamias, foliar spraying of herbicide is not recommended.

In contrast, the use of growth regulators has proven effective for mistletoe control in some settings (Berry et al. 1989, Watson and Martinez-Trinidad 2006, but see Robbins et al. 1989; Adams et al. 1993). Phosphonic acid of Ethephon (Ethrel®) is an ethylene-generating compound, which has the potential to induce ripening and improve nut abscission. Its use for mistletoe control has been trialled in the USA to regulate Phoradendron species (Viscaceae) in a variety of stone fruit and nut tree species, including pecans (Joyce et al. 1987). In landscape trees, applying Ethephon at label rates effects partial abscission of mistletoe shoots, but mistletoe plants are not killed and the approach is advocated as means of slowing the intensification of existing mistletoe infections by reducing mistletoe fruiting (Lichter et al. 1991).

Other chemical approaches to mistletoe control have been trialled, including soil active herbicides, synthetic amino acids, copper sulfate, triclopyr ester and other contact herbicides, all with either highly variable results or negative effects on host trees (Coder 2003). Although the possibility of using hormones arose in several discussions with growers, the only plant hormone that's been trialled for mistletoe control is ethylene. Likewise, several growers inquired about the viability of mistletoe control via 'sterility-inducing chemicals'. Ongoing research has explored the possibility of inducing sterility via selective breeding (e.g., in the tropical forage plant *Leucaena leucocephala*) but this approach has never been explored with any mistletoe.

Mechanical

Although necessarily labour-intensive, mechanical removal of mistletoes by pruning infected branches is the single most effective method to control mistletoes in macadamia orchards. This is representative of other horticultural crops affected by mistletoe elsewhere, including the USA where considerable research has been conducted evaluating alternative approaches (Brown 1959; Shamoun 1998; Shamoun and DeWald 2002).

Mistletoes in the genera *Dendrophthoe, Benthamina* and *Muellerina* all share the same growth habit, epicortical runners emerging laterally from the original connection with the host and forming secondary attachments both distal and proximal to the original haustorium (Fig. 29). Successful removal of these mistletoes requires removing all of these connections. While this can be achieved by cutting the infected host branch beneath (upstream) of the most proximal connection, discussions with growers revealed that alternative techniques may allow the mistletoe to be removed without removing the entire branch. Thus, once the distal portion of the infected branch is removed, cutting into the macadamia bark at the site of each attachment and stripping away the mistletoe vascular tissue can be effective. Further R&D would need to determine whether follow-up with a herbicide and/or growth regulator could minimise resprouting of mistletoe residue before any permit could become available for their use.

To be effective, mechanical removal needs to be both thorough, regular, and coordinated across adjacent properties, necessitating access to tree canopies and detection of mistletoes. To ensure safe work practices, access to mistletoe in the upper crown requires cherry pickers, boom-lifts or other machinery. Mechanized pruning the shapes the sides and tops of trees will remove mistletoe foliage, but follow up pruning specifically to remove mistletoes is required, especially for *Dendrophthoe* species which frequently grown epicortical runners down infected branches into the centre of the crown.

Fig. 29. Severely pruned young mistletoe trees, approximately 12 months after mistletoes were removed. Photograph by Melinda Cook.

Once removed from trees, mistletoe plants and infected branches are typically piled between trees rows, and then either recovered and relocated for chipping and composting, or chipped in situ and distributed as mulch directly beneath the macadamia trees. Given the high concentration of cations and other nutrients in mistletoe tissues (March and Watson 2007; 2010), this latter approach is recommended. In addition to reduced handling, chipping pruned mistletoes and branches in situ will retain all nutrients within the orchard, and may also have added benefits of fostering any insects, fungi and other natural enemies of mistletoe within the more infected parts of the orchard.

Biological

As with chemical control, research in other plant systems (both horticulture and forestry) have explored the use of biological control to manage mistletoes (Askew et al. 2006). A wide range of hyperparasitic fungi naturally occur on mistletoes, with successful control of some dwarf mistletoes achieved via spraying host crowns with fungal inoculant. Rather than necessarily killing mistletoes, these pathogens reduce plant vigour and interrupt phenology. These approaches have been discussed by Australian forest scientists, but, as with chemical control, they have not been found to be effective to control Loranthaceous mistletoe in Australian settings. Likewise, some exploratory research has evaluated the potential for bacterial agents to control mistletoes, but results were inconclusive and vary depending on microclimate.

Although no documented trials have been conducted using insects to effect biological control of mistletoes in horticultural crops (either in Australia or elsewhere), macadamias are well suited to trialling this approach. Given the diversity and specificity of insects known to feed on mistletoe (Figs 30, 31) and the widespread adoption of biological control to manage insect pests by macadamia growers, investigating the potential for insects to help control mistletoes in macadamia orchards is a priority. In addition to identifying likely candidate species, this research would need to be conducted in close consultation with growers to incorporate the timing of insecticide application to control other orchard pests.

Fig 30, 31. Imperial Jezabel (left) one the eight jezabels (*Delias* spp.) is Australia. All favour mistletoe plants as hosts, with their large caterpillers frequently defoliating entire mistletoe clumps. Satin Azure Butterfly (right), a species which lays its eggs exclusively on mistletoes and also depends on mistletoe nectar as a food source. Photograph by David Cook (left) and Kerry Stuart (right).

Other approaches

Many other approaches to controlling mistletoes in horticulture, forestry and ornamental trees have been explored, including flame throwers and controlled burns, freezing, bagging infected branches with plastic bags, and plant breeding to select for mistletoe resistance (Brown 1959; Kelly et al. 1997). Most of this research has been small-scale trials conducted in the USA, in coniferous forests and plantations infected with dwarf mistletoe, and none have the demonstrated efficacy or large-scale relevance to be considered viable control measures for macadamia growers.

Longer-term management

Mistletoe has emerged as a significant issue for macadamia growers, affecting tree growth, yield and interfering with routine orchard operations. Effective control of mistletoes requires increased awareness of the issue, coordinated actions across the macadamia industry, exchange of information among growers regarding treatment, and the development of best-practice treatment techniques based on quantitative trials. As native plants, eradicating mistletoes at large scales is neither possible nor permissible. Rather the objective is to suppress mistletoes within macadamia orchards to maximize profitability. The treatment options discussed represent short-term reactive solutions to manage existing infections. Longer term management necessitates proactive approaches to document patterns, understand the mechanistic basis of observed patterns, test the effectiveness of different treatment regimes and estimate the cost effectiveness of applying them at different scales.

Variety selection

Different varieties of macadamias exhibit different susceptibility to mistletoe infection. Comparisons of rates of infection within growing areas will identify those species most susceptible to infection. When choosing between macadamia varieties for planting new orchards, these differences need to be explicitly considered and communicated to stakeholders. Thus, choosing to plant a variety with low susceptibility to mistletoe infection that may have lower yields or slower growth rates may end up being far more profitable than higher yielding but more susceptible varieties given differences in management to remove mistletoes over the life of those trees.

Tree health (balancing yield with susceptibility)

Orchard management is necessarily about maximizing profitability—balancing improvements in yield with the associated costs at the whole-of-orchard scale. To inform these decisions, different approaches to mistletoe management need to be fully costed and integrated with all other aspects of orchard operations. Fertilizer and water use may affect the likelihood of macadamias becoming infected with mistletoes, so different fertilizer application rates or watering regimes need to be compared in terms of both yield and mistletoe management.

Canopy management

Some orchard operations conducted to improve yield may inadvertently increase susceptibility of macadamias to mistletoe infection. Thus, removing interior branches and trimming tree crowns to increase light penetration and fruit set necessarily increases germination success of mistletoe seeds. While some of these differences in canopy closure relate to variety selection, comparisons of mistletoe infection in trees of the same variety receiving different canopy management will reveal the magnitude of any association. This will also be critical to develop best practice guidelines for orchard management that incorporate the effects of different management regimes on mistletoe infection rates, enabling grower-specific cost-benefit calculations to be made to safeguard long term profitability.

Awareness

A critical component of managing mistletoe in macadamia orchards is raising awareness of the issue at all levels of the industry, from seasonal workers all the way to investors. Unlike some other pests that can have immediate impacts on yield or nut quality, mistletoes are more gradual but, by the time large plants are common in the orchard, management is time consuming and costly. Developing dynamic posters summarizing key elements of mistletoe management and associated information sheets and online resources is a priority to increase awareness among orchard staff. For owners and investors, property-scale comparisons of different approaches to managing mistletoe and effects on yield and overall profitability over multiple years will be critical to demonstrating the need to incorporate mistletoe management into routine orchard operations.

Knowledge sharing

Macadamia growers have tried a wide range of solutions, and there will be many innovative management techniques and novel approaches to treating infected macadamias that will be relevant to some growers. Grower workshops are one way to facilitate knowledge sharing, but a targeted program to solicit input from growers and compile that information into a coherent and accessible summary would be both beneficial and timely. In addition to showcasing practical solutions to detecting, treating or avoiding mistletoe in macadamia orchards, this synthesis would clarify those gaps in our understanding which are of greatest relevance to growers, and key priorities for further work.

RECOMMENDATIONS

Effective control of mistletoe in Macadamia orchards is best achieved by applying the principles of integrated pest management: monitor to identify the problem, evaluate whether treatment is required, prevent problems through proactive practice, action to address problems, and then monitoring to evaluate efficacy. Integrating current understanding of mistletoe life history, seed dispersal and ecological interactions with growers' priorities, recommended mistletoe management involves five priorities.

1. Treat existing infections

Mechanical removal (pruning macadamia branches infected with mistletoe) is presently the most effective means of controlling mistletoe in Macadamia orchards. By cutting off infected branches below the lowest point of attachment, existing mistletoes are removed, and all waste material chipped and used as mulch. If any points of attachment remain, re-sprouting is likely. For those infections on the trunk or main branches, prune off all mistletoe shoots and cut away macadamia bark around attachment points. Rather than removing mistletoes during regular pruning of trees, mistletoe removal is best conducted independently when mistletoes are flowering, maximising detectability and reducing mistletoe fruit abundance within orchards.

2. Minimize reinfection

In addition to regularly removing mistletoe from established trees, reinfection should be minimized by adjusting canopy management. By encouraging more continuous canopies, germination of mistletoe seeds is impeded. Those canopy management practices aiming to minimise pest and disease pressure and increase fruit set and nut yield (especially removing interior branches to open up tree crowns) may exacerbate mistletoe infection in orchards with established mistletoe plants, so any improvements in yield need to be considered in terms of increased costs associated with detecting and removing mistletoe.

3. Reduce susceptibility

Varieties with more open canopies (including 816, 203, A16, A4, A38, 344) are more susceptible to mistletoe infection, compared to other varieties (including 661, 846, 741) that have a more contiguous canopy and more upright growth habit. Trees at the ends of rows and in orchards planted at lower density are more likely to become infected. Bird deterrents may help in reducing seed dispersal,

4. Early detection

Detecting mistletoe is a priority, both to identify those areas requiring management but also for evaluating efficacy and optimal frequency of existing management practices. For large scale growers and orchard managers, locating mistletoes is best conducted by specialist teams (including using drone-borne near Infra-red imagery. Smaller-scale growers should involve orchard workers where any mistletoe detected during orchard operations is flagged, either physically or digitally, to be followed up by removal teams once a pre-determined threshold is reached at either the block or whole-of-orchard scale.

5. Increase awareness

Incorporating mistletoe control into routine grower management systems and coordinating control measures across adjacent properties is essential to minimize impacts of mistletoe on tree health and decrease rates of reinfection. Targeted research is required to evaluate determinants of susceptibility and inform development of best practice control protocols.

FURTHER RESEARCH

Although pecans and several species of tree grown in plantation forestry and as ornamentals in Australia are affected by mistletoe, little research has investigated control measures. Likewise, although considerable work has been conducted on mistletoe control measures for other systems, this relates to different plants (most is focused on mistletoes in the Viscaceae rather than Loranthaceae) and has minimal applicability to Australian settings. There are many open questions regarding mistletoe in macadamia orchards, with investment in strategic research recommended to address these knowledge gaps, working cooperatively with growers to develop best-practice guidelines to treat existing infections, reduce susceptibility and minimize effects of mistletoe on orchard profitability.

Chemical management and delivery options

Evaluate the efficacy of different herbicide and growth regulator treatments, both with and without mechanical pruning to determine concentration, application technique, and timing that is most effective in controlling mistletoe. In addition to evaluating effectiveness in initial control and the likelihood of re-sprouting, estimating the cost, safety, off-target effects, residues and any trade implications of different control options will provide the information needed to determine whether these chemicals will be appropriate for use in managing mistletoe in macadamias.

Determinants of susceptibility

A series of trials will help clarify whether periodic water shortage affects already infected trees, either by reducing mistletoe growth or minimizing mistletoe flowering and subsequent fruiting. Manipulating fertigation regimes (especially reducing rates of Phosphorous application) will clarify the role of host nutrition on mistletoe infection, establishment, growth and phenology.

Seed dispersal

Establishing which bird species are the principal seed dispersers in different growing areas will inform a better understanding of how new infections arise and how existing infections intensify. This work should be conducted in both macadamia orchards and adjacent shelterbelts and native vegetation, evaluating whether birds dispersing mistletoe seed into macadamias are coming from other infected macadamia orchards, and have learned to associate macadamias with ripe mistletoe fruit. Efficacy of bird deterrents should be trialled, especially in those orchards where they are already in use to reduce nut loss.

Potential for biological control

Surveys of orchards and adjacent areas with differing levels of mistletoe infection in different growing areas will establish which insects, fungi and other natural enemies are likely candidates for biological control of mistletoes. While mistletoe populations in shelterbelts and native vegetation may act as seed sources, mistletoe populations in areas adjacent to macadamia orchards may boost populations of beneficial insects, especially specialist moths and butterflies that rely on mistletoes as larval food plants. Trials should be conducted in consultation with growers to evaluate effects of existing orchard management (including the use of beneficial insects and spraying regimes of fungicide and pesticides) on insects and fungi associated with mistletoes. The role of mistletoes in supporting pollinators, parasitoids and other beneficial insects should also be investigated, including evaluation of whether retaining mistletoe in vegetation adjacent to macadamia orchards may boost populations of beneficial insects.

Mistletoe detection

Surveys at night (using LED lights) and during peak mistletoe flowering are effective for detecting mistletoes visible from the ground, but it is unknown what proportion of infected trees and mistletoes are missed. Trials of different approaches to detecting mistletoe in the canopies of macadamia trees should be conducted, comparing ground-based surveys with aerial imagery, both from satellite photography and drone-borne near-infrared imaging systems.

REFERENCES AND BIBLIOGRAPHY

Adams, DH, Frankel SJ, Lichter JM. 1993. Considerations when using ethephon for suppressing dwarf and leafy mistletoe infestations in ornamental landscapes. *Journal of Arboriculture* **19**: 351–357.

Anderson SJ, Braby M. 2009. Invertebrate diversity associated with tropical mistletoe in a suburban landscape from northern Australia. *Northern Territory Naturalist* **21:** 2–23.

Appiah, AA, Owusu GK. 1997. Cocoa Mistletoes—A Review. Proc. 1st International Cocoa Pest and Diseases Seminar (pp. 98–107). Accra, Ghana, 1995.

Askew SE, Shamoun SF, van der Kamp BJ. 2006. Development of a biological control strategy to mitigate hemlock dwarf mistletoe in retention silviculture systems: *Colletotrichum gloeosporioides* – western hemlock dwarf mistletoe pathosystem. B.C. *Journal of Ecosystem Management* **7**: 23–29.

Aukema JE, Martínez del Rio C. 2002. Where does a fruit-eating bird deposit mistletoe seeds? Seed deposition patterns and an experiment. *Ecology* **83:** 3489–96.

Beilharz V. 1997. Fungal pathogens of mistletoes in Victoria. *Victorian Naturalist* **114**: 162–163.

Bernhardt P. 1984. Mistletoes on mistletoes: the floral ecology of *Amyema miraculosum* and its host, *Amyema miquelii* (Loranthaceae). *Australian Journal of Botany* **32**, 73–86.

Berry, A.M., Han, S.S., Dodge, L.L., Reid, M.S., & Lichter, J.M. 1989. Control of leafy mistletoe (*Phoradendron spp*.) with ethephon. Proceedings of the first annual conference of the Western Plant Growth Society, Ontario, CA. (1/18-19). B

Braby MF. 2006. Evolution of larval food plant associations in *Delias* Hübner butterflies (Lepidoptera: Pieridae). *Entomological Science* **9**: 383–398.

Brown AG. 1959. Mistletoe control on a large scale. *Journal of the Australian Institute for Agricultural Science* **25**: 282–286.

Brown AG, Greenham CG. 1965. Further investigations in the control of mistletoe by trunk injections. *Australian Journal of Experimental Agriculture and Animal Husbandry* **5**: 305-309

Burns AE, Cunningham SA, Watson DM. 2011. Arthropod assemblages in tree canopies: a comparison of orders on box mistletoe (*Amyema miquelii*) and its host eucalypts. *Australian Journal of Entomology* **50**: 221–30

Burns A, Taylor G, Watson DM, Cunningham S. 2015. Diversity and host-specificity of Psylloidea (Hemiptera) inhabiting box mistletoe, *Amyema miquelii*, and three of its host Eucalyptus species. *Austral Entomology* **54**: 306–314

Calder M and Bernhardt P. 1983. *The Biology of Mistletoes*. Academic Press, Sydney.

Canyon DV and Hill CJ. 1997. Mistletoe host-resemblance: a study of herbivory, nitrogen and moisture in two Australian mistletoes and their host trees. *Australian Journal of Ecology* **22:** 395–403.

Carnegie, Bi H, Arnold S, Li Y and Binns D (2009) Distribution, host preference, and impact of parasitic mistletoes (Loranthaceae) in young eucalypt plantations in New South Wales, Australia. *Botany* **87:** 49–63.

Choate JH, Andrews RH and Barlow BA. 1987. Herbivory and cryptic mimicry in Australian Loranthaceae. In *Parasitic Flowering Plants.* (Eds HC Weber and W Forstreuter) pp. 127–135. Philipps-Universitat, Marburg, Germany.

Coder KD. 2003. Treating Mistletoe (*Phoradendron serotinum*) in trees, University of Georgia School of Forest Resource, publication FOR 03-10: 2. C

Cook, M. 2017. *Spatial memory, search images and environmental cues: how do frugivores find ripe mistletoe fruits?* (Masters Thesis). School of Life Sciences, University of Technology Sydney

Downey PO. 1998. An inventory of host species for each aerial mistletoe species (Loranthaceae and Viscaceae) in Australia. *Cunninghamia* **5:** 685–720.

Ehleringer JR, Cook CS, Tieszen LL. 1986. Comparative water use and nitrogen relationships in a mistletoe and its host. *Oecologia* **68**: 279–284.

Glatzel G, Balasubramaniam S. 1987. Mineral nutrition in mistletoes: general concepts, pp. 263–276. In H. C. Weber and W. Forstreuter [eds.], Proceedings of the 4th International Symposium of Parasitic Flowering Plants, Philipps-Universitat, Marburg, Germany.

Greenham CG, Brown AG. 1957. The control of mistletoe by trunk injection. *Journal of the Australian Institute for Agricultural Science* **23**: 308–318.

Greenham CG, Brown AG. 1959. Mistletoe control. *Journal of the Australian Institute for Agricultural Science* **25**: 73.

Hawkins BA, Thomson JR, Mac Nally, R. 2018. Regional patterns of nectar availability in subtropical eastern Australia. *Landscape Ecology* **33**: 999–1012.

Hawksworth F. 1983. Mistletoes as forest parasites. In *The Biology of Mistletoes*. Edited by M. Calder and P. Bernhardt. Academic Press, Sydney, Australia. pp. 317–333.

Hawksworth FG, Johnson DW. 1989. Biology and management of dwarf mistletoe in lodgepole pine in the Rocky Mountains. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. USDA Forest Service General Technical Report RM-169.

Hawksworth, FG, Shaw CG. 1984. Damage and loss caused by dwarf mistletoe in coniferous forests of western North America. In *Plant Diseases: Infection, Damage, and Loss.* Edited by R.K.S. Wood and G.J. Ellis. Blackwell, Oxford, UK. pp. 285–297.

Hawksworth FG, Wiens D. 1996. Dwarf mistletoes: biology, pathology, and systematics. USDA Forest Service,Washington, D.C. Agriculture Handbook 709.

Johansen K, Tu Y, Searle C, Wu D, Phinn S. 2018. Mapping the condition of macadamia tree crops using multi-spectral drone imagery. UAVG 2017 Conference abstract

Joyce DC, Rein K, Berry AM, Reid MS. 1987. Control of broadleaf mistletoe (Phoradendron tomentosum) with dormant season ethephon sprays. *Acta Horticulturae* **201**: 141–144.

Kelly P, Reid N, Davies I. 1997. Effects of experimental burning, defoliation and pruning on survival and vegetative resprouting in mistletoes (*Amyema miquelii* and *A. pendula*). *International Journal of Plant Science* **158:** 856-861

Kope HH, Shamoun SF. 2000. Mycoflora associates of western hemlock dwarf mistletoe plants and host swellings collected from southern Vancouver Island, British Columbia. *Can. Plant Dis. Surv*. **80**: 144–147.

Kuijt J, 1969, *The Biology of Parasitic Flowering Plants*. University of California Press, Berkeley.

Lamont B. 1985. Host distribution, potassium content, water relations and control of two co-occurring mistletoe species. *Journal of the Royal Society of Western Australia* **68:** 21–25.

Lichter JM, Reid MS, Berry AM. 1991. New methods for control of leafy mistletoe (*Phoradendron* spp.) on landscape trees. *Journal of Arboriculture* 17: 127–130.

Maes W, Huete A, Avino M, Boer M, Dehaan R, Pendall E, Griebel A, Steppe, K. 2018. Can UAV-based infrared thermography be used to study plant-parasite interactions between mistletoe and Eucalypt trees? *Remote Sensing* **10**: 2062

March WA and Watson DM 2007. Parasites boost productivity: effects of mistletoe on litter dynamics in a temperate Australian forest. *Oecologia* **154:** 339–347.

March WA and Watson DM. 2010. The contribution of mistletoes to nutrient returns: evidence for a critical role in nutrient cycling. *Austral Ecology* **35**: 713–721

Mast AR; Willis CL; Jones EH; Downs KM, Weston PH. 2008. A smaller Macadamia from a more vagile tribe: inference of phylogenetic relationships, divergence times, and diaspore evolution in Macadamia and relatives (tribe Macadamieae; Proteaceae). *American Journal of Botany*. 95: 843–870.

Minko G, Fagg PC. 1989. Control of some mistletoe species on eucalypts by trunk injection with herbicides. *Australian Forestry* **52**: 94–102.

Moss JT and Kendall R. 2016. *The Mistletoes of Subtropical Queensland, New South Wales and Victoria*. Butterfly and Other Invertebrates Club, Runcorn Qld.

Murphy SR, Reid N, Yan ZG. Venables WN. 1993. Differential passage time of mistletoe fruits through the gut of honeyeaters and flowerpeckers—effects on seedling establishment. *Oecologia* **93**, 171–176.

Norton DA, Stafford-Smith M. 1999. Why might roadside mulgas be better mistletoe hosts? *Australian Journal of Ecology* **24:** 193–198.

O'Hare P, Stephenson RA, Quinlan K, Vock N. 2004. *Macadamia Grower's Handbook*. Queensland Department of Primary Industries and Fisheries, Nambour, Queensland.

Petrović K. 2014. *Herbivory of the common brushtail possum (Trichosurus vulpecula, Marsupialia: Phalangeridae) at different scales of resource heterogeneity.* (PhD thesis), School of Environmental Science, Charles Sturt University, Albury.

Press MC, Graves, J. D., & Stewart, G. R. (1990). Physiology of the interaction of angiosperm parasites and their higher plant hosts. Plant Cell Environ., 13, 91-104.

Ramsfield TD, Shamoun SF, van der Kamp BJ. 1999. Fungal parasites of lodgepole pine dwarf mistletoe in British Columbia. *Canadian Journal of Plant Pathology* **21**: 204.

Rawsthorne J, Watson DM and Roshier DA. 2012. The restricted seed rain of a mistletoe specialist. *Journal of Avian Biology* **43**: 9–14

Rawsthorne J, Watson DM and Roshier DA 2011. Implications of movement patterns of a dietary generalist for mistletoe seed dispersal. *Austral Ecology* **36**: 650–55

Reid N. 1986. Pollination and seed dispersal of mistletoes (Loranthaceae) by birds in southern Australia. In *The Dynamic Partnership: Birds and Plants in Southern Australia.* (Eds HA Ford and DC Paton) pp. 64–84. Government Printer, South Australia.

Reid N. 1989. Dispersal of mistletoe by honeyeaters and flowerpeckers: components of seed dispersal quality. *Ecology* **70**: 137–145.

Reid N, Fittler J. 2008. Results of mistletoe pruning and pollarding trials for Southern New England Landcare and Meat & Livestock Australia. Ecosystem Management, University of New England, Armidale, NSW, Australia.

Reid N, Fittler J, Kar A, Storey A, Cook T. 2008. Effect of spray applications of several herbicides on the mortality of box mistletoe (*Amyema miquelii*) and host saplings (*Eucalyptus blakelyi* and *E. melliodora*). Ecosystem Management, University of New England, Armidale, NSW, Australia.

Reid N, Stafford Smith M, Yan Z (1995) Ecology and population biology of mistletoes. In *Forest Canopies.* (Eds MD Lowman and NM Nadkarni) pp. 285–310. Academic Press, San Diego.

Rietman LM, Shamoun SF, van der Kamp BJ. 2005. Assessment of *Neonectria neomacrospora* (anamorph *Cylindrocarpon cylindroides*) as an inundative biocontrol agent against hemlock dwarf mistletoe. *Canadian Journal of Plant Pathology* **27**: 603–609

Robbins K, Johnson DW, Hawksworth FG, Nicholls TH. 1989. Aerial application of ethephon is ineffective in controlling lodgepole pine dwarf mistletoe. *Western Journal of Applied Forestry* **4**: 27–28

Shamoun SF. 1998. Development of biological control strategy for management of dwarf mistletoes. In Proceedings of the 45th Western International Forest Disease Work Conference. 15–19 September 1997. Compiled by R. Sturrock. Pacific Forestry Centre, Prince George, BC, Victoria, B.C., Canadian Forest Service. pp. 36–42.

Shamoun S.F, DeWald LE. 2002. Management strategies for dwarf mistletoes: biological, chemical and genetic approaches. In *Mistletoes of North American conifers*. Technical coordinators B.W. Geils, J.C. Tovar, and B. Moody. Rocky Mountain Research Station, USDA, For. Serv., Gen. Tech. Rep. RMRS-GTR-98. pp 75–82.

Shamoun SF, Ramsfield TD, van der Kamp BJ. 2003. Biological control approach for management of dwarf mistletoes. *New Zealand Journal of Forest Science* **33**: 373–384.

Sidahmed OA. 1984. Incidence of mistletoe (Loranthus spp.) on citrus and guava trees in the central region of the Sudan. *Acta Horticulturae* **143**: 417–420.

Watson DM. 2001. Mistletoe—a keystone resource in forests and woodlands worldwide. Annual Review of Ecology and Systematics 32: 219–249.

Watson DM 2004. Mistletoe—a unique constituent of canopies worldwide. In *Forest Canopies*. 2nd edn. (Eds M Loman and B Rinker) pp. 212–223. Academic Press, New York.

Watson DM. 2009. Determinants of parasitic plant distribution: the role of host quality. *Botany* **87:** 16–21.

Watson DM. 2011. *Mistletoes of Southern Australia*. CSIRO Publishing

Watson DM. 2016. Fleshing out facilitation—reframing interaction networks beyond top-down versus bottom-up. *New Phytologist* **211**: 803–808.

Watson DM, Rawsthorne J. 2013. Mistletoe specialist frugivores: latterday 'Johnny Appleseeds' or self-serving market gardeners? *Oecologia* **172**: 925–932

Watson WT, Martinez-Trinidad T. 2006. Strategies and treatments for leafy mistletoe (*Phoradendron tomentosum*) suppression on dedar elm (*Ulmus crassifolia*). *Arboriculture & Urban Forestry* **32**: 265–270.

Wicker EF, Shaw CG. 1968. Fungal parasites of dwarf mistletoes. *Mycologia* **60**: 372–383.

Wiens D, Calvin CL. 1987. Epiparasitism in mistletoes. *Golden Bough* 1: 2–4.

Wood BW, Reily CC. 2004. Control of mistletoe in pecan trees. *Horticultural Science* 39: 110–114

Zaroug MS, Abbasher AA, Zahran E, Elagab, MA. 2009. Occurrence of mistletoe (*Tapinanthus globiferus*) (A. Rich.) van Tieghan on orchards in central Sudan. In: Proceedings of the 10th World Congress on Parasitic Plants, 10–12 June 2009 (D. Rubiales, J. Westwood and A. Uludag eds.). Pp. 64, Kusadasi, Turkey