IPM in Avocados
(South-West Western Australia)

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Contents

Executive Summary

This report describes an Integrated Pest Management (IPM) strategy suitable for dealing with the range of pests of avocados in south-west Western Australia. It addresses the requirements for controlling pests that are currently of concern but also how control strategies may need to change if the pest spectrum alters or pesticide resistance develops.

The report also provides a summary of pollination in avocado orchards. It looks at current practice and research into improving pollination and the range of species that might be potential pollinators.

Avocado growers in south-west Western Australia currently face fewer pests than growers in other parts of Australia and consequently insecticide and miticide use is generally much less. The absence of fruit-spotting bugs in particular is a major advantage for growers in the south-west. The main pest in this region is six-spotted mite and although not all growers apply miticides for this pest, the larger orchardists would generally apply an IPM compatible miticide which will kill the pest but not disrupt biological control agents or insect pollinators. In some cases this may be occurring as a precautionary or 'just in case' application to prevent the likelihood of an outbreak. The main concern here is potentially losing this miticide due to development of insecticide resistance. Registration of other IPM compatible miticides would slow the onset of resistance while retaining good IPM. If non-IPM compatible miticides are applied then problems with secondary pests are likely, as has occurred elsewhere in avocado production and in many other crops.

This report discusses biological and cultural control options for the range of pests nominated by local growers. Rather than insecticide-based strategies, these control methods are currently the mainstay of pest management in south-west WA and ideally should remain so. Methods used to encourage biological control agents can also encourage potential pollinators, including honeybee, blowflies, and hoverflies.

Honeybees are used in avocado orchards however they are not all that attracted to avocado flowers and are easily drawn away to other flowers they find more desirable. Wild pollinators in a range of different genera and species are particularly useful for helping improve avocado pollination so continuing practices that encourage diversity and increased abundance of wild pollinators would be beneficial to help improve fruit set. Obviously, insecticide or miticide applications could also negatively impact insect pollinators so maintaining the current status of minimal pesticide use is critical. This could be of course by killing them directly, but sub-lethal effects that might disrupt foraging activity, reduce egg-lay or reduce longevity can also be of importance, so maintaining the current status of minimal pesticide use is critical.

Background

This project was commenced in response to a request for tenders by the South West NRM with regard to **'Creating an Integrated Pest Management Strategy for avocado orchards in the SW of WA'.** The objective of this project is the development of a management strategy on how best to manage pesticide use, and what vegetation management and / or vegetation restoration strategies around the orchard can benefit insects including pollinators, in avocado orchards in the SW of WA.

Items of particular interest in this project are as follows:

- What are the pests of avocados in SW WA orchards;
- What beneficial insects will be useful in controlling these pests;
- How to encourage beneficial insects;
- What cultural controls would be useful;
- What chemicals are effective without impacting beneficials, including pollinators; and
- What vegetation management or restoration around the orchard would benefit pollinators.

Methodology

The starting point for any IPM strategy is to determine the pest spectrum that exists. Following that, the relevant biological, cultural and pesticide control options can be identified and an integrated control strategy can be developed. We proposed that the best way to do this is to use a combination of literature review and discussion with industry contacts (farmers and advisors). The discussions were conducted as interviews (via Zoom or by phone) with individual growers and advisors. This approach is one that IPM Technologies has used successfully in many different crop types and it allows a strategy to be developed around pests that growers nominate as being of concern and match these with available control options that are relevant and available. It also allows any gaps in knowledge or problems with control of particular pests to be identified (eg. use of broad-spectrum insecticides) and for future control options to be included (eg. pesticides that are not currently registered).

Growers who were interviewed in this project were nominated by South West NRM (Wendy Wilkins) and included relatively small-scale and also large-scale growers of avocados. We also interviewed Lachlan Chilman (Biological Services) as he has been involved in research trials with WA Dept of Primary Industries and Regional Development in recent years looking at potential biological control of pests of avocados. Dr David Cook (DPIRD) also provided information on his recent studies on the use of different species of flies as potential pollinators of avocados.

Cultural control options are those that either discourage pests or favour beneficial species. The management of the inter-row area is something that is an extremely important element of IPM in crops such as vineyards and pome fruit orchards, for example. In this study, we examined the potential for utilising the inter-row to encourage not only the biological control agents of pests but also potential pollinators. Honeybees are the most well-known pollinators but in many crops the role of non-bee pollination is underestimated. We discussed with growers, advisors and researchers the potential for using certain plants to encourage pollinators as well as biological control agents.

IPM

An IPM approach involves integrating biological, cultural and pesticide control options in a compatible way, for the range of pests that occur in any crop. The easiest way to present this is as a four-column table as described by Page and Horne (2012) in their book “Controlling Invertebrate Pests in Agriculture”. Such a table is presented (Table 1) for the full range of pests that occur in Australian avocado crops (including areas such as northern NSW and Queensland). This list includes species that do not occur in south-west Western Australia and so a separate strategy has been developed for this region (Tables 2 – 5). In these tables the pesticide options are colour-coded for their compatibility with the key beneficial species listed in column 2 and is not a comment on either their effectiveness or whether or not they should be applied as part of a non-IPM approach.

In this scenario, fruit-spotting bugs are considered a serious pest with broad-spectrum insecticides commonly used to combat them. It is highly likely that pests such as mites, thrips and scale are flared as a result of these sprays through the consequent loss of natural enemies that would otherwise keep them in check. While this pest is extremely unlikely to ever establish in south-west WA it is important to point out what can happen if disruptive insecticides are used.

Table 1. Example of an IPM strategy for Avocados (national)

(From Page (2021): Report to Hort Innovation; Project AV19001; Review and extension of avocado pests and their management)

September 2021 Red – Harmful to beneficials, Blue -Moderately harmful, Green - Safe

<table>
<tr><th>Pest</th><th>Beneficial</th><th>Cultural</th><th>Pesticide
(not necessarily registered)</th></tr>
<tr><td>Fruit spotting bug</td><td>Ansastatus,
Pred.bugs
Spiders, Robber flies</td><td rowspan="7">Release Anastatus into susceptible varieties, hedgerows

Canopy management

Tree Height

Tree density

Inter-row management

Decrease Dust

Inter-row planting</td><td>Lepidex, Lannate, Bulldock
Transform, Trivor, Sivanto</td></tr>
<tr><td>Mites</td><td>Predatory mites and thrips
Ladybird species</td><td>Abamectin, Paramite
Apollo, Vendex</td></tr>
<tr><td>Planthoppers</td><td>Uncertain</td><td>Carbaryl</td></tr>
<tr><td>Loopers</td><td rowspan="2">Parasitic flies and wasps
Predatory bugs
Lacewings</td><td rowspan="2">Lannate, chlorpyrifos
Spinetoram
Dipel, Altacor
Prodigy;
Vivus (Heliothis only)</td></tr>
<tr><td>Heliothis</td></tr>
<tr><td>Thrips</td><td>Predatory thrips and mites</td><td>Transform, Spinetoram</td></tr>
<tr><td>Scale</td><td>Parasitic wasps, ladybirds</td><td>Trivor, Oils</td></tr>
</table>

In south-west WA fruit spotting bugs are not present and so the pest spectrum is much less and the use of insecticides is very different. We asked selected growers and advisors from WA about what they considered to be the pests of importance and how they dealt with them. Table 2 lists the pests of concern.

Table 2: Avocado pests in south-west WA.

Pest	**Beneficial**	**Cultural**	**Pesticide** (not necessarily registered)
6-spotted mite			
Garden weevil and whitefringed weevil*			
Black beetle*			
Snails (conical and garden snails)			
Latania scale			

* Only pests on young plants at establishment

Six-spotted mite = *Eotetranychus sexmaculatus*

Garden weevil = *Phlyctinus callosus*

Whitefringed weevil = *Naupactus leucoloma*

Black beetle = African black beetle = *Heteronychus arator*

Conical snail = *Cochlicella acuta*

Garden snail = *Cornu aspersum* (also previously known as *Helix aspersa*)

Latania scale = *Hemiberlesia lataniae* a small, armoured scale insect.

This list of pests is a much smaller one than those in Table 1, with some pests only a concern at planting or on very young plants (weevils, African black beetle) and some pests (snails and scale insects) present but are more potential pests rather than current major pests. Six-spotted mite can be a serious pest in avocados of WA (WA Farm Note 2022) but many growers do not spray for it as it can be present but not cause economic losses.

Table 3: Biological control options for Avocados in south-west WA

Pest	**Beneficial**	**Cultural**	**Pesticide** (not necessarily registered)
6-spotted mite	Predatory mites *Stethorus* ladybirds		
Garden weevil and whitefringed weevil	-		
Black beetle	Carabid beetles		
Snails (conical and garden snails)	-		
Latania scale	Wasps, lacewings, predatory mites		

The list of beneficial species consists mostly of naturally occurring species, although predatory mites can be purchased from commercial producers of biological control agents.

Table 4: Cultural Control options for Avocados in south-west WA.

Pest	**Beneficial**	**Cultural**	**Pesticide** (not necessarily registered)
6-spotted mite	Predatory mites *Stethorus* ladybirds	Healthy plants Hygiene Inter-row management	
Garden weevil and whitefringed weevil	-	Inter-row management	
Black beetle	Carabid beetles	Inter-row crops (oats)	
Snails (conical and garden snails)	-	Control weeds, inter-row	
Latania scale	Wasps, lacewings, predatory mites	Nectar sources	

Cultural controls are management practices that can impact favourably on biological control agents or that can discourage pest species. Managing the inter-row space to reduce dust, provide a pollen and nectar source for beneficial species and to reduce weeds that favour pests are all important control options. (Dust can disrupt biological control agents such as predatory mites). Having healthy plants, selecting suitable varieties, and having good farm hygiene are also well accepted factors limiting the impact of pests.

Table 5: Control options for pests of Avocados in south-west WA.

September 2021 Red – Harmful to beneficials, Blue -Moderately harmful, Green - Safe

Pest	**Beneficial**	**Cultural**	**Pesticide** (not necessarily registered)
6-spotted mite	Predatory mites *Stethorus* ladybirds	Healthy plants Hygiene	?Vertimec Vendex
Garden weevil and whitefringed weevil	-	Inter-row management	Avatar, on young plants only
Black beetle	Carabid beetles	Inter-row crops (oats)	Lorsban or Suscon at planting
Snails (conical and garden snails)	-	Control weeds, inter-row	Baits
Latania scale	Wasps, lacewings, predatory mites	Nectar sources	White oil

There are no highly disruptive pesticides listed in this final table, which is very different to the list in Table 1. Two pesticides used at planting or only on very young plants (Avatar and Lorsban) would be highly disruptive to beneficial species if used as a foliar spray on mature plants. The fact that they are not used on older plants is important.

The lack of disruptive pesticide applications is important in maintaining good populations of beneficial species and avoiding the flaring of secondary pests such as scale and mites. However, the risk of pests such as 6-spotted mite becoming resistant to the currently used miticides (particularly *Vendex*) is very real and one grower interviewed for this study thought that resistance was already present. There is a need to either increase the use of biological or cultural options and potentially obtain permits or registration of other IPM compatible miticides.

In addition to killing biological control agents and pollinators, sub-lethal impacts such as shorter longevity, reduced egg lay and changing behaviour (including foraging behaviour) can be serious consequences of some pesticides. Some fungicides, for example Mancozeb, can also disrupt predatory mites.

Flowering and Pollination of Avocados

In comparison to many other horticultural crops, avocados have quite an unusual flowering behaviour. The flowers are hermaphroditic, having both male and female parts, however they open as each sex separately. During the flowering process a flower will only open twice, and numerous flowers will begin their opening sequence every day during the flowering period. Flowering typically occurs over several weeks in spring.

Each flower will open first as a female (stamens up) for a few hours before closing again. Later, the same flower re-opens as a male (stamens splayed out) for a few hours before closing for the final time. In general, all open flowers on a single tree will be synchronised, and as such they will either all be functionally male or all functionally female at one point in time. This type of flowering is referred to as synchronous protogynous dichogamy. Flowers open separately in time (dichogamy) and release pollen only after the stigma has been receptive for a period of time (protogyny).

Avocado cultivars are grouped into two types, referred to as Type A or Type B, depending on when the flowers are in the female or male phases. Type A (cultivars include Hass and Reed) flowers typically open as female in the morning, then as male in the afternoon of the following day. Type B (includes Shepard, Fuerte, and Bacon) are generally in the female phase in the afternoon and reopen as males releasing pollen the following morning.

This flowering process encourages cross-pollination (between different cultivars) when polliniser trees are included in orchard plantings. While self-pollination (within a flower) is possible, the protogynous dichogamy flowering minimises its occurrence (Ish-am & Eisikowitch, 1993). However, close-pollination (neighbouring flowers on the same tree or cultivar) is quite common and can occur during the daily overlap period of male and female-flowering (Ish-Am, 2005). Climatic conditions can interrupt the process of flower synchronisation and under cooler temperatures, the period over which open male and female flowers can overlap can increase considerably.

It is common for orchards to be planted with Hass only, as close-pollinated Hass can still yield well. There is research however that suggests inter-planting Hass orchards with polliniser species (i.e. type B flowering variety) could increase overall yields in terms of fruit per tree through reduced fruit abscission rate, as long as pollinisers are planted in close proximity (Degani, et al., 1989; Kobayashi et al., 2000). The benefits of pollinisers is observed to be of particular benefit in growing regions with cool springs (Bender, 2002).

A mature avocado tree can produce a significant number of flowers, often more than a million over a single flowering period. Fruit set rates however are consistently reported to be around 0.3% or lower (Dixon and Sher, 2002; Evans et al., 2010) even under optimal growing and pollination conditions. Hand pollination trials in avocado have been shown to record about 5% fruit set (Evans et al., 2010), likely when more than 50 pollen grains are deposited per flower (Pattemore et al., 2020). This suggests that pollination is potentially limiting yields in many avocado production systems.

While there have been some studies that suggest wind pollination is the dominant mechanism for pollen transfer, it is generally referred to as being non-effective (Ish-am & Eisikowitch, 1993; Dymond et al., 2021).

The Importance of Insects as Pollinators of Avocados

The separation in time of the male and female phases as well as the fact that flowers produce nectar, have a long period of pollen viability and other features of the pollen grain itself, suggests that insect pollinators play an important role for moving pollen between flowers. Other studies have also shown that without insect pollinators, pollination and fruit set are significantly reduced (Pérez-Balam et al., 2012; Ish-Am et al., 1999).

Pollinators

Potential species

Potential pollinators that have been reported to visit avocado flowers include honeybees, stingless bees, wasps, flies, beetles, true bugs and moths.

In Australia and most other regions of the world, honeybees (*Apis mellifera*) have generally been considered to be the most important pollinators for avocado (Vithanage, 1990; Ish-am & Eisikowitch, 1993). It is however widely recognised that honeybees are not very attracted to avocado flowers and will readily divert to nearby flowers more attractive to them. While the reasons for this are not fully understood it has been suggested to be related to the flowers' nectar composition and the concentrations of particular minerals (Afik et al., 2006).

In central America where avocado originated, Ish-Am et al. (1999) identified stingless bees (Meliponini) as the primary avocado pollinator. In other regions, bumble bees (*Bombus terrestris*) have been reported as an efficient avocado pollinator (Ish-Am & Eisikowitch, 1993; Ish-am et al., 1998). While species of stingless bees and *Bombus terrestris* are present in other regions of Australia they are unfortunately not found in south west Western Australia.

Recent research in the tri-state region of Australia determined that wild non-bee pollinators were the dominant pollinator species for avocado (Howlett, 2017). Some of the key species included many blowfly (Calliphoridae) species, hoverflies (Syrphidae), ladybird beetles and rhiniid flies (Rhiniidae). The study identified the bristle fly (Tachinidae) along with honeybees as being the most efficient insect pollinators, measured in terms of pollen to stigmas per minute. However, the wild pollinators were more effective due to their sheer abundance. Blowflies (Calliphoridae) and hoverflies (Syrphidae) are commonly reported as key visitors to avocado flowers and important pollinators (Dymond et al., 2021; Howlett, 2017; Read et al., 2017).

While other insects including plant bugs, gnats, craneflies, moths and lacewings have been observed visiting avocado flowers and carrying pollen, how useful they are as actual pollinators is largely unknown (Ish-Am et al., 1999; Pattemore et al., 2018; Buxton et al., 2023).

For pollination to be successful the pollinator insect needs to visit both the male and female flowers and carry pollen on their body. Insect species with more hair on their body typically tend to attach and carry more pollen. It is important however, that wherever the pollen is carried on the insect's body is also an area that comes into contact with flower anthers and stigmas. It is also ideal that the insect travels somewhat widely across numerous trees to carry out cross pollination if polliniser trees are present within the orchard.

The avocado flower is a single seed crop which means that the flower ovary holds only one ovule. In theory, a single pollen grain should be enough to achieve fertilisation and subsequently result in fruit development. It is generally understood that 5-12 pollen grains are required for fertilisation however numerous research projects have demonstrated that 20 pollen grains or more are required to reach the stigma for a high fertilisation probability (Ish-Am, 2005; Evans et al., 2010; Pattemore et al., 2020). Therefore, the higher the number of pollen grains deposited onto the stigma, the higher the chance of pollination success and fruit-set.

David Cook (DPIRD in WA; pers. comm.) suggests that most insects (bees, blowflies and the hoverfly *E. tenax*) transfer just over an average of 1-1.2 grains of pollen per single visit and other small hoverflies transfer less than one pollen grain per visit. Since each avocado flower requires a minimum of 5 pollen grains for successful pollination to occur, a single flower visit by an insect is often not enough.

Managing and encouraging pollinators

Honeybees (*Apis mellifera*)

There are many factors that influence the efficiency of honeybees in pollinating avocado trees. Some of the issues and research into the use of bees as pollinators are described here.

Inadequate pollination is still common in avocado, even when managed honey bee colonies are placed in an orchard (Evans et al., 2010; Pattemore et al., 2020). Honeybees are not the natural pollinators of avocados and are easily distracted by other flowers more attractive to them. They are, however, likely to contribute quite significantly to pollination in the Australian environment. Their importance is evident in many published studies in other parts of the world that do show a significant positive correlation between bee activity on avocado trees with fruit set and thus yield (Vithanage, 1990; Ish-Am and Eisikowitch, 1998; Peña and Carabalí, 2018; Sagwe, 2022).

Pollen loads on honeybees visiting female 'Hass' trees in Australia and New Zealand has been reported at times to be low. In a study by Pattemore et al. (2020) looking at honey bees in New Zealand and Australian avocado orchards it was found that 47.1% and 73.7% of bees had fewer than 5 pollen grains respectively, and these poor pollen loads have been associated with the poor fruit set.

A different trial conducted for the same study a year later found the majority of honeybees caught in this trial were carrying more than 100 pollen grains, and nearly 40% were calculated to be carrying over 1000 pollen grains. However, pollen deposition on the flowers visited by these bees remained low with nearly 70% of flowers having no pollen grains deposited.

Honeybees tend to have greater pollen loads when caught on male-phase polleniser flowers (Type B cultivars) than when caught on female-phase 'Hass' flowers. In comparison, bumble bees and flies showed no difference in pollen loads between cultivars, suggesting that they were more likely to move between cultivars than bees (Pattemore et al., 2020).

Bees have also been shown to have limited efficiency in cross pollination with most of the field worker bees foraging on 1-3 avocados trees at a time, and therefore only able to cross-pollinate trees within closer distances (Ish-Am, 2005). There is a small percentage of the foraging honey bees (2%-4% of the population), which are known as 'scout bees' that will travel further and may carry avocado pollen much further away.

Honeybees can also be less active in cooler inclement weather including rain and in cloudy conditions which can restrict pollination activity during these conditions.

Recommended hive stocking rate for avocados varies between 4-9 per hectare depending on who you speak to and what you read. Ish-Am (2000) suggests that 1 hive per ha is rarely sufficient, and in many cases 4 hives are required. Avocado orchards pollinated by six hives per hectare increased 40% in fruit production per tree in comparison to orchards without hives (Peña and Carabalí, 2018). A hive allocation rate of 6 hives per ha compared to 4 per ha had significantly higher density of bees per tree, pollination rate and weight of fruits per tree, however the total number of fruits per tree was similar (Peña and Carabalí, 2018). While there does seem to be a lack of information regarding optimal stocking densities for hives in avocado orchards, 4-6 hives per ha seems to be a rate that will benefit the orchard and not become cost prohibitive.

Placement of hives is critical and will significantly impact how efficient the bees are at pollinating avocados. It is important to ensure hives are spread throughout the orchard giving just enough distance apart so they are not competing for the same avocado resources. They should also be placed in a sunny area protected from wind, and a decent distance away from neighbouring crops or bushland that may have competing flowering species. Ensuring bees have a water source they can safely access without travelling too far is also essential. Monitoring bee activity around the orchard and on trees during blooming time can help determine that there are enough hives and that they are well placed. Ish-Am (2005) suggests that at least 5-10 honeybees per medium tree on the female bloom should be observed to achieve a fair pollination.

According to Trevor Monson (from Monson's Honey and Pollination) honeybees can be encouraged to be more active in collecting avocado pollen if they are fed within the hive with a 33-36% sugar syrup (pers. comm). Feeding honeybee colonies on sugar syrup within the hive has been shown to increase the total amount of pollen that honeybees collect on kiwifruit (Goodwin, 1986) another crop also not that attractive to bees. Trevor has also suggested that using hives that are strong, but without too much honey, and with room to expand could also help pollination in avocado orchards (pers comm.).

Introducing hives once flowering has commenced is beneficial for providing a food source for the bees. Goodwin (2012) recommended the introduction of hives when the crop presented between 5 and 10 % of flowering. Staggering hive introduction (a few hives per week for example) could also be of benefit as there are not too many bees all at once when food resources are lower, reducing the risk of them flying elsewhere looking for food.

Flies (Diptera)

Flies can be efficient pollinators as they tend to be active in variable weather conditions, move randomly through an orchard, and visit both male and female flowers (Cook et al., 2020). Flies are most often after nectar as a sugar source to aid in flight and since many species generally have quite hairy bodies, pollen sticks to them in the process. This allows them to distribute pollen while regularly visiting flowers. Blowflies (Calliphoridae), hoverflies (Syrphidae) and houseflies (Muscidae) have been associated with providing pollination to crops including avocados (Cook et al., 2020; Pérez-Balam et al., 2012; Ish-Am et al., 1999; Howlett, 2017; Read et al., 2017).

In central America, the oriental blue fly, *Chrysomya megacephala*, was reported to contribute significantly to avocado pollination (Pérez-Balam et al., 2012; Ish-Am et al., 1999). While this species is present in Australia it hasn't been noted as a species of interest in avocado pollination. A recent review of avocado pollinators in the tri-state region of Australia, identified bristle flies (Tachinidae) as being the most efficient wild pollinator species in terms of delivering the most pollen to stigmas per minute (Howlett, 2017), however many other fly species were also observed in this study and were also considered to have pollination benefits for avocados. Blowflies were identified as the species most frequently visiting avocado flowers, (species including the lesser brown blowfly (*Calliphora augur*), large green blow fly (*Chrysomya rufifacies*), brown blow fly (*Calliphora stygia*), and the Australian sheep blowfly, *(Lucilia cuprina*)) together acting as a significant pollinator. Other important species identified in this study included hoverflies (narrow yellow hoverfly (*Simosyrphus grandicornis*), black orange hoverfly (*Melangyna viridiceps*), Muscidae flies, Rhiniidae flies and ladybird beetles. This study and several other studies have indicated that hoverflies (Syrphidae) and blowflies (Calliphoridae), visit avocado flowers and can carry quite large pollen loads, however they are less efficient pollinators than honeybees due to their lower flower visitation rate (Howlett 2017, Pattemore et al., 2020; Ish-Am et al., 1999; Vithanage, 1990). Their large populations during avocado flowering and activity even in inclement weather makes up for this however and renders them as very important pollinating species (Howlett, 2017; Ish-Am et al., 1999). One grower interviewed for this project noted that when high populations of hoverflies are observed in the avocado orchard, pollination tends to be good, but whether this is due to the hoverflies themselves or whether this represents a healthy wild pollinator activity for the season remains unknown.

In south-west WA there has been recent work on the use of flies as pollinators in avocados (David Cook, pers.comm.). This project has identified that both the European bluebottle (*Calliphora vicina*) and the western blue-bodied blowfly (*Calliphora dubia*) are capable of pollinating avocados when placed in large enclosures around 25-35 avocado trees (mostly Hass but also with 10% polliniser or Type B cultivars). The best result to date was in Pemberton in a particularly cold and wet flowering season (2021), when bees were not as active due to the weather. In this instance *C. dubia* pollinated more avocado flowers than bees and all other insects in the open orchard. In Busselton in the same season (2021), both *C. vicina* and *C. dubia* showed the ability to pollinate avocado at rates equivalent to the bees in the open orchard. Thus so far it seems that these blowfly species can do well in a cooler, wet flowering season as compared with warmer flowering seasons, where bees were able to pollinate around twice as many avocado flowers than blowflies. These data are yet to be published.

Using flies for pollination in avocados and other crops is still a relatively new area of research. There certainly appears to be a large opportunity for having a diverse mix of fly species within avocado orchards to assist in pollination, particularly blowflies and other calliphorid flies. Many of these species feed on meat and can cause issues in livestock such as fly-strike to sheep. Some producers have used roadkill or meat to breed up pollinating fly species in greenhouses and paddocks, however this obviously needs to be well managed and planned to avoid issues such as attracting vermin, causing risk to neighbouring livestock and unfavourable odours.

Hoverfly species are often commonly regarded as an important pollinating species, as the second most important pollinator group after bees (Cook et al., 2020). The most abundant hoverfly species found visiting avocado flowers in the tri-state region of Australia were *Simosyrphus grandicornis* and *Melangyna viridiceps* and according to growers, these species tend to often be found in avocado orchards in south-west WA. The populations of these species can fluctuate year on year likely due to environmental and climatic causes. The adults of these species are nectar feeding but the larvae feed on aphid prey. Having a diverse species of flowering plants in an orchard can help increase these hoverfly populations by providing an alternative nectar source for adults, while also potentially hosting various aphid species as food for juveniles.

One other important hoverfly species are drone flies (*Eristalis* spp.) and while these haven't been identified as a key species for pollinating avocados there is evidence that they do visit avocado flowers and carry avocado pollen (Read et al., 2017; Howlett, 2017). According to David Cook (pers comm.) adult *E. tenax* feed very readily on avocado flowers for over 1 minute on each avocado flower extracting nectar and as a consequence pick up pollen that can be transferred to an open female flower. Trials with the hoverfly *E. tenax* are on-going nationally and within the south-west WA region. Part of this research is also looking at its potential to be reared in the field and used as a managed pollinator species for a wide range of crops. Their larvae are referred to as 'rat tailed maggots' and live in stagnant water feeding on organic material which can be placed in situ in the field (Howlett, 2017).

Other species

Hymenoptera species, other than honeybees, have been found visiting avocado flowers and carrying pollen including wasps and ants (Howlett, 2017; Ish-Am et al., 1999). Read et al., (2017), identified *Lasioglossum spp* and other Hymenoptera visiting avocado flowers in New Zealand. The Mexican honey wasp (*Brachygastra mellifica*) has also been identified as a contributor to avocado pollination in central America (Pérez-Balam et al., 2012; Ish-Am et al., 1999). Wasps and ants however are often not large contributors to pollination as their bodies are commonly hairless and do not carry much pollen.

The South West region of Western Australia is home to several species of native bees. Most of these species are solitary bees, meaning that they do not live in colonies like honeybees. Some of the most common species found in this region include: Blue-banded bee (*Amegilla cingulata*), Teddy bear bee (*Amegilla bombiformis*), *Megachile spp*. including Leafcutter bees and Resin bees, *Lasioglossum* spp., and Carpenter bees (*Xylocopa spp*.). Read et al. (2017), identified *Lasioglossum spp*. visiting avocado flowers in New Zealand and *Lasioglossum spp* have been collected in Avocado orchards in south-west WA *(Insect survey reports, South West Catchments Council, unpublished data).* All of these bees are recognised as being important pollinators of crops and native plants. There are however no published data and very minimal information online that could be reliably sourced to indicate that these species pollinate avocado. It is highly possible however that they could contribute to pollination while not being a key pollinator species for avocado.

Pattemore et al. (2018) and Buxton et al. (2023), both found evidence in New Zealand that moths (Lepidoptera) may play an important role in the pollination of avocado flowers, particularly in cool weather or temperate regions when low overnight temperatures result in female flowers being open overnight. Pattemore et al. (2018) also showed that insects such as wood gnats, crane flies, scarab beetles, capsid bugs, and brown lacewings did carry avocado pollen and also visited avocado flowers during the night.

In Australia, transverse and variegated ladybird beetles were found to carry significant pollen in Australia and visited both male and female avocado flowers. The abundance of the transverse ladybird beetle resulted in it being quite an effective pollinator species (Howlett, 2017). In New Zealand, longhorn beetles (*Zorion guttigerum*; Cerambycidae) were frequently found on avocado flowers (Read et al., 2017), however pollen data were not collected.

There is certainly the potential for a wide range of other species including beetles, moths and other small insects to help improve pollination in avocado orchards. Supporting and maintaining a diverse insect species population within avocado orchards is certainly likely to improve overall pollination and crop yields. This can be achieved by providing diverse plant species within inter-rows or on boundaries, reducing inter-row mowing intervals and minimising the use of pesticides.

Cultural controls for Pest Management and Pollination

Cultural controls are simply management techniques that either influence beneficial species in a positive way or discourage pest populations. Inter-row management can be important in both of these regards. For example, reducing dust and providing a nectar source favours beneficial species while reducing weeds and maintaining good farm hygiene reduces the impact of pests. In addition, there is potential to use the inter-row area to grow plants that encourage pollinators. Some of the pollinator species (for example hoverflies) will also be biological control agents for pests.

The availability of a more attractive bloom outside of the flowering avocado orchard can greatly reduce the numbers of bees foraging on your crop. For this reason, establishing new avocado orchards away from other crops such as citrus that flower at the same time is widely recommended. Having flowering species within the orchard that are attractive to the bees can however keep bees moving within the orchard rather than out of it and thus can be of benefit.

While specifically planting more plant species around the orchard can be beneficial, managing weeds and allowing some to flower or reducing mowing of the inter-rows, possibly only mowing every second row each time, can also be very useful. Planting of different species in inter-rows or as boundary or hedge rows does require careful investigation to determine the most appropriate species, planting time and combinations of annuals and perennials as well as flower colors and shapes (Nicholls and Altieri, 2013). The inclusion of native plants will typically attract more native pollinators and also provide more suitable shelter for different life stages (Nicholls and Altieri, 2013).

There are two local related projects that we are aware of currently looking at this topic in south-west Western Australia. South West NRM has two projects funded under the Australian Government's National Landcare Program. One is looking at revegetation on farms using a mix of species that provide continuous food and shelter for pollinators, and the other project will identify key pollinators in avocado orchards in the South West region of WA and develop and disseminate information about management practices to enhance numbers of pollinators in the orchards.

Plants suitable for Pollinators

Clovers, brassicas, sunflowers, borage and plants in the mint and daisy families are well known to be attractive to honeybees and other pollinators. Yellow and white flowers have been shown to elicit feeding in hoverflies and buckwheat, mustard, yarrow, (*Achillea millefolium)* fennel and sweet alyssum have been documented as being attractive to hoverfly species (Kloen and Altieri 1990;

Colley and Luna, 2000; Lövei et al., 2009, Hogg et al., 2011). *Phacelia tanacetifoliahas* also been shown to attract Syrphid fly populations (Hickman and Wratten, 1996), and in Australia barley and oats are known to attract aphids which in turn attract and breed hoverfly species. Howlett (2017) suggested that an avocado grower in Western Australia was trialling a combination of barley, phacelia, coriander and alyssum to help improve hoverfly populations.

Buckwheat has been found to maintain a huge insect diversity attracting over 170 different insect species (Kulikov and Naumkin, 2004). While some of these are pest species, there is also quite a large number of pollinating insects attracted to its flower. Bees are particularly attracted to it as are adult hoverflies (Syrphidae), soldier flies (Stratiomyidae) and large flies from the Tachinidae, Sarcophagidae, Muscidae families. Buckwheat is fast growing and easy to establish but does not tolerate cold weather.

Sowing cover crop mixes can effectively extend the flowering period and attract a broader range of insect species. In the UK, a cover crop mixture sown to borage, buckwheat, cornflower, mallow, pot marigold, and phacelia attracted a diversity of flower-visiting insects including bees, flies and moths (Carreck and Williams, 2002). This trial found that by sowing this mix at different times throughout the year, more food was available for pollinators when other crop sources were low and that different insect species favoured different sowing dates (Carreck and Williams, 2002).

Deliberately planting certain types of plants can have multiple effects. For example, planting cereals will assist with control of pests such as weevils and African black beetle and also reduce weeds that can favour pests.

However, care should be taken to ensure that as well as plantings having the desired effect that they do not have an unforeseen detrimental effect. For example, planting legumes has positive effects with nitrogen fixation but can favour populations of whitefringed weevil. If plantings of any inter-row species become dense then they could favour populations of slugs and snails. Snails in particular could become a serious issue if the populations become large and they move up into the trees. Unlike slugs they would be able to over-summer in the trees and cause damage in springtime. In addition, some of these species such as brassica and buckwheat can set lots of seed and can grow in a range of conditions, so it is important to be careful that these don't become problematic weedy species.

It is particularly important to avoid the use of insecticide or miticide applications when possible, to minimise harm done to non-bee pollinators that could be active day and night at different times through the season. While these products can directly kill insects with contact, they can also have sub-lethal effects that might disrupt foraging activity or reduce egg lay or longevity.

Acknowledgements

We would like to thank all of the people that took the time to be interviewed for this project, including Lachlan Chilman from Biological Services. We particularly thank Dr David Cook (DPIRD) for providing updated information on his studies on the use of flies as pollinators. Janet Horne provided helpful comments on drafts of this report.

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