Final report

Project title:

Expansion of flies as berry and cucurbit crop pollinators

Project leader:

Romina Rader

Delivery partner:

University of New England and seedPurity

Report author/s:

Romina Rader, Cameron Spurr, Raylea Rowbottom, Abby Davis and Lena Schmidt

Project code:

MT22007

Date:

2026

Disclaimer:

Funding statement:

Expansion of Flies as berry and cucurbit crop pollinators has been funded using the Blueberry, Rubus and Vegetable research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

Published and distributed by: Horticulture Innovation Australia Limited
ABN 71 602100149

Level 15
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

Contents

Public summary

Insect pollination is a critical ecosystem service underpinning the productivity, quality, and economic value of many high-value horticultural crops. High pollinator dependency is particularly evident in berry and cucurbit systems, where effective pollen transfer is essential for achieving optimal fruit quality. In both crop groups, inadequate pollination can result in reduced fruit size, deformities, or complete crop losses, directly impacting grower profitability and consistency of supply. This project evaluated the pollination performance of two eristalini flies, the common drone fly, *Eristalis tenax* and the golden fly, *Eristalinus punctulatus*. The project also evaluated the potential for habitat augmentation (aquatic pools and floral interrow strips) to promote wild fly pollinators and beneficial insects in berry crops and explored opportunities for alternative pollinator species for cucurbit crops.

In blueberry, raspberry and blackberry, we conducted cage and polytunnel trials (New South Wales) and open release trials (Tasmania) to test *E. tenax* efficiency. Concurrently, wild pollinators were recorded using field transects in both berries and cucurbits and habitat augmentation was conducted in blueberry. We also determined optimal fly stocking rates and investigated strategies for deployment and integration into commercial production systems.

Average foraging activity of *E. tenax* was generally lower in raspberry and blueberry than blackberry. This may be because individual flies foraged on fewer flowers and for shorter periods of time. In both raspberry and blackberry trials, *E. tenax* foraged most actively at lower temperatures (22^{o}C and below). In Blackberry, the drone fly, *E. tenax* was found to be an effective pollinator under commercial conditions, producing fruit comparable in size and quality to that achieved within the current (primarily bee-serviced) commercial pollination system. In raspberry and blueberry, *E. tenax* pollinated flowers and produced commercial grade fruit, but on average, fruit weight was ~1g lighter compared to bee pollination. *Eristalis tenax* provided consistent pollination services at cooler temperatures in all three berries suggesting these managed flies may be particularly valuable for early spring and winter production cycles.

Several wild bee taxa were abundant flower visitors to some cucurbit crops at particular locations and we found that basil and other co-flowering herbs attracted many wild flower visitors to the sites where cucurbits are grown. Cage trials of *E. tenax* revealed poor performance as a potential managed pollinator of pumpkin and zucchini.

While use of *E. tenax* as a standalone blackberry pollinator may become feasible as commercial rearing capacity develops, its application in berry crops is likely strongest as a complimentary managed pollinator to honeybees. Our work highlights the potential benefits that combined stocking of honeybees and *Eristalis tenax* as managed pollinators could deliver for blackberry growers. This stems from the fact that the two species forage optimally under different environmental conditions. *Eristalis tenax* performs best under cooler conditions, whereas honeybees are most active under warmer conditions. Furthermore, as *E. tenax* can be deployed directly into berry tunnels, they are able to service the crop when honeybees are less likely to leave their hives for example for example on windy days or during periods of rainfall. In this way, complimentary stocking of both species may extend the range of conditions under which blackberries are effectively pollinated, and this could improve fruit yield and quality outcomes for growers.

Keywords

Cucurbits, Rubus, Blueberry, Pollination, hoverflies, *Eristalis tenax,* fly, Diptera, bee, pollinator, berries

Introduction

Many cucurbit and berry crops are dependent on insects to transfer pollen to achieve high-quality fruit. These crops represent a substantial and growing component of Australian horticulture. Despite their economic importance and reliance on insect pollination, these systems are vulnerable to inconsistent pollination services. Ensuring reliable and effective pollination in berry and cucurbit crops is essential for supporting the long-term resilience and profitability of these industries.

While global pollination research and industry practice have largely focused on managed honeybees, a diverse assemblage of wild pollinators, including flies, contribute substantially to crop pollination (Orford et al 2015; Rader et al 2016; Rader et al 2020). Flies contribute to crop pollination both as managed pollinators in protected cropping systems and as wild, free-living taxa in open environments (Currah & Ockendon, 1983; Jauker & Wolters 2008; Saeed et al 2016; Hodgkiss et al. 2018; Stavert et al 2018; Howlett & Gee, 2019; Cook et al. 2020a; Sánchez et al. 2022a; Sánchez et al. 2022b; Cook et al 2023), yet their contribution to commercial crop production systems has historically been under-recognised. Many taxa, particularly syrphid (hover) flies, possess traits functionally similar to bees, including hairy bodies that facilitate pollen transfer and a reliance on flower nectar and pollen (Stavert et al 2016; Gaffney et al 2018; Cook et al 2020b; Davis et al 2023). Unlike bees, flies often remain active under a broader range of environmental conditions, including cooler temperatures, variable weather, and lower light levels, allowing them to provide pollination services when bee activity is limited (Howlett 2012; Brittain et al 2013; Rader et al. 2013; Kühsel & Blüthgen 2015; Goodwin et al. 2021; Miyashita et al. 2023). These features position flies as valuable supplementary or alternative pollinators, particularly in systems where pollination is inconsistent or constrained.

The inclusion of other resources in farming landscapes can also support pollinators for longer periods. Co-flowering plants such as forage strips established within or adjacent to crop rows, represents a practical, scalable strategy to support pollinator nectar and pollen needs (Carvalheiro et al 2014). These plantings provide continuous and diverse floral resources that support pollinator nutrition and attraction, particularly during periods when crop flowers are limited or less attractive (Sutherland et al 2001; Haene et al 2009; Villa et al 2016). By increasing floral diversity within fields, forage strips can enhance pollinator community composition and support a broader range of taxa, including flies, wasps, birds, beetles and ants. In addition to floral resources, many native pollinators use other habitats for nesting and reproduction, including large tree hollows, river-banks, ponds and decaying vegetation. Supporting a wide variety of animals can increase the chances that they pollinate as adults and perform additional ecosystem services such as predation of pests or decomposition of organic matter (Fijen et al 2022). For example, syrphid fly larvae can be biological control agents of aphids (Jirón-Pablo et al 2018; Dunn et al 2020; Pekas et al 2020; Van Oystaeyan et al 2022), decomposers of organic materials (Martínez-Falcón et al 2012; Sanchez Matos et al 2021), and bioindicators of healthy ecosystems (Sommaggio 1999). Despite this potential, a key limitation remains the relatively limited understanding of the efficiency of flies as pollinators in commercial cropping systems, and the resources required to sustain their populations, particularly during immature life stages (Rader et al. 2020; Davis et al 2023). Addressing these knowledge gaps is critical for enabling the reliable integration and scaling of flies as managed pollinators in Australian horticulture production.

This report builds on previous research investigating flies as managed pollinators under the project Managing flies for crop pollination (PH16002) and extends this work into berry and cucurbit production systems as model crops. By examining pollinator activity, crop visitation, and pollination outcomes across these systems, this project aimed to better define the role of flies in agricultural landscapes and evaluate their potential to contribute to more resilient and diversified pollination strategies for Australian horticulture. Specifically, the project focused on identifying optimal field release strategies for mass-reared *Eristalis tenax* (Syrphidae) in berry systems, developing approaches to attract wild fly pollinator populations, and improving retention of released flies within cropping environments. In parallel, the work explored opportunities to diversify managed pollinator taxa in berry production, while also identifying and evaluating if there are alternative pollinator species for cucurbit crops. Finally, the project investigated habitat augmentation strategies to support these alternative pollinators, with the aim of enhancing both pollinator persistence and pollination service delivery across crop systems.

Cucurbit Trials

With nearly 1,000 species covering tropical, subtropical and temperate regions, the Cucurbit (or gourd) family comprise a diverse variety of floral forms and fruit from small ornamental gourds such as cucumbers, squash and miniature melons to large fruits including pumpkins, cantaloupe and watermelon. Our research focus was on pumpkin and zucchini crops which are typically grown annually and rely heavily on insect pollination for successful fruit set. This is because each pollen grain produces only one seed and insufficient pollen deposition can result in small misshapen fruit. At flower, cucurbits typically produce male flowers early and continue to be produced throughout the season, while female flowers tend to open later as daylength increases and are often fewer in number than male flowers. The opportunity for successful pollination only lasts a single day with unsuccessfully pollinated flowers are aborted. The current strategy for pollination of cucurbit crops is by provision of honeybees and wild pollinators, however, with the incursion of varroa mite in Australia in 2024, the subsequent loss of many hives and ongoing damage from varroa on wild pollinators there is a requirement to investigate the potential of managed flies as pollinators in cucurbits. Our research focus was to determine the efficiency of flies as complementary managed pollinators for pumpkin and zucchini and investigate pollinator diversity visiting these crops.

Methods

Research Locations and Cultivars

The potential for Eristalini flies to pollinate pumpkin crops were evaluated in cage-based field trials in November, 2023 and 2024 (*Eristalis tenax*) and an open field release in November, 2024 (*Eristalinus punctulatus*) at a large field at Morpeth in New South Wales (32.8° S, 151.6° E) in a crop of cultivar 'Sampson' (*Cucurbita maxima*). Daily temperature and rainfall data during each trial are shown in Figure 1. A follow up small cage-based shade house trial evaluating both species as pollinators of pumpkin cultivars 'Kent' (*Cucurbita moschata*) and 'Jarrahdale' (*C. maxima*) and zucchini cultivar 'Blackjack' (*Cucurbita pepo*) was conducted at Margate in southern Tasmania in December, 2024. During the 6-day observation period of this trial, daily maximum and minimum temperatures were cooler than at the Morpeth site, ranging from 19.8 to 21°C and 6.2 to 13.2°C respectively with 1 day of significant rainfall (15.1mm) recorded on the second last day.

Pollinator surveys on cucurbits were across two distinct geographical areas of NSW, at three small-scale market gardens in the Newcastle-Maitland region from November 2023 to April 2024 (32.8° S, 151.6° E) at and in the Hawkesbury region (33.6° S, 150.7° E) from September 2024 to March 2025 across nine commercial farms. Cucurbit plant species surveyed in the Newcastle-Maitland region consisted of zucchini (*C. pepo*), pumpkin (*C. moschata* and *C. maxima*), cucumber (*Cucumis sativus*), melon (*Cucumis melo*), and mouse melon (*Melothria scabra*). In the Hawkesbury region, cucurbit crops surveyed included pumpkin cultivars: 'Butternut' (*C. moschata*) and 'Sampson' and zucchini cultivars: 'Rosa', 'Goldie', 'Eva', and 'Nitro'.

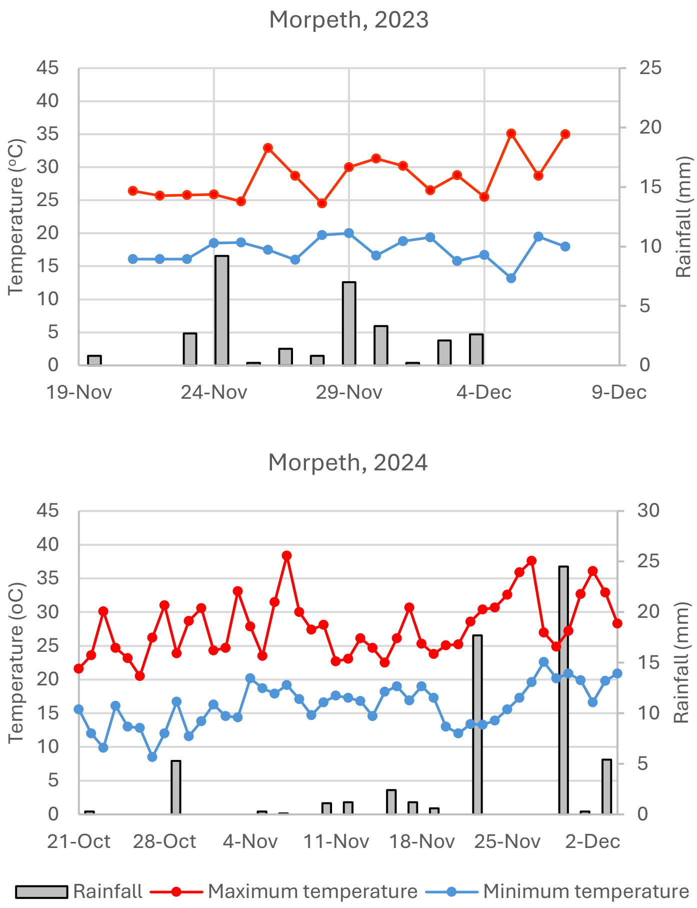

Figure 1: Daily temperature and rainfall data during the Morpeth pumpkin cage pollination trials in 2023 and 2024.

Efficacy of Eristalinae Flies as Pollinators of Pumpkin and Zucchini

Morpeth trials (2023 and 2024)

The trial area in both years consisted of a 1.6 ha pumpkin crop. We erected four 3.5m x 8m (28m^2 enclosed net tunnels covering between 11-13 plants per cage (Plate 1 a). In 2023, *Eristalis tenax* was stocked into cages at 10 pupae/m^2 with this stocking rate doubled in 2024. Pupal hatching rates were scored weekly. Fly foraging activity surveys were conducted hourly on two days per week over a 2 to 3 week period. Each survey was conducted from 3 positions in each cage, with foraging scored on both male and female flowers (Plate 2 a). To compare hoverfly and open field-pollination, supplemental hand- and open-pollination treatments were applied weekly in both the enclosed net tunnels and in control 'open pollinated' plots adjacent to each cages in field. The supplemental hand-pollination treatment was designed to estimate fruit set under conditions of unlimited pollination. It was conducted by brushing dehisced anthers from male flowers over receptive stigmas of female flowers (Plate 2 b). In the open pollinated treatment, receptive flowers were tagged and left for pollination either by the hoverflies (within the net cages) or insects present in the open field. Fruit that set within the cages and open plots was harvested 4 weeks post flower and weighed.

In 2024, we conducted an open release of *Eristlainus punctulatus* in the open crop (Plate 1 b) to establish whether this species, which is better suited to hotter and drier climatic conditions typical of those experienced during the trials at Morpeth, would perform better than *E. tenax*. The stocking comprised 8,000 pupae placed in a single, central release box within the field on the 14th of November. Following the release, we scored pupal hatching rate and surveyed for foraging pollinators along 12 transects, each 25m in length, located around the perimeter of the crop. In total, 6 surveys were made over an 8 day period.

Plate 1: a) Set up of the Maitland field cages for *E. tenax* pollination efficiency trials, 2023; b) Release box in the centre of the 1.6 ha pumpkin crop for deployment of *E. punctulatus* in 2024 and c) Overview of the 2023 pumpkin trial block during flowering. Images by Karen Santos and Raylea Rowbottom

Plate 2: a) Side profile of a male (left) and female (right) Samson pumpkin flowers and b) the process of supplementary (hand) pollination. Images by Raylea Rowbottom

Shadehouse Pollination Trial

A follow up small cage trial was conducted at in a shade house at seedPurity in Margate, Tasmania in December 2024, to collect data on the behaviour of *Eristalis tenax* and *Eristalinus punctulatus*, on flowering pumpkins and zucchinis under different climatic conditions. Six, 12m² cages were constructed over pumpkin cultivars 'Jarra' and 'Kent', and zucchini cultivar 'Blackjack' allocated to two cages each (four potted plants per cage). One cage of each pair was stocked with *E. tenax* and the other with *E. punctulatus* at 8 flies/m^2. Behavioural observations commenced immediately after introduction and continued daily between 10:30 and 14:00 for 5 days. Assessments included counts of male and female flowers within the cage, total fly abundance per cage, and five-minute focal observations of individual fly movement (n = 16 total; 8 per species).

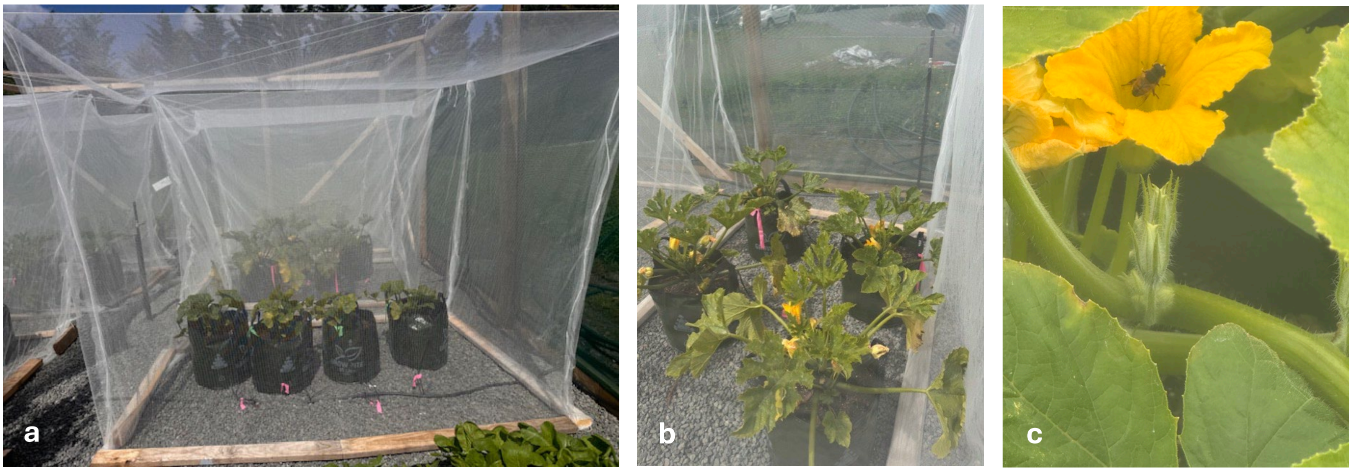

Plate 3: a) Cages erected withing the shadehouse at Margate, Tasmania 2024 showing 4 poly bags of cucurbit plants and drip irrigation system for each plant; b) Image showing the plants in flower, and c) Observation of *E. tenax* emerging from a male flower.

Wild Pollinator Evaluation

We evaluated wild pollinator visitors to cucurbits in the above Morpeth commercial cucurbit farm as well as small farms that grew cucurbits for market stalls in Maitland and in the Hawkesbury region of NSW (hereafter referred to as 'market plots'). Fieldwork targeted morning anthesis (typically 6:00-12:00; up to 15:00 in market gardens), and this methodology was applied consistently across all farms in both the Newcastle–Maitland and Hawkesbury regions. In market plots, cucurbits were planted in small plots amongst other produce. We chose 1-3 plants to observe flowers simultaneously during surveys. Honeybee hives were not located on the properties of the market plots. In commercial pumpkin fields in the Newcastle-Maitland region, eight 50m transects were established along the edge of crop fields to conduct surveys. In the Hawkesbury region, where crop plots were smaller than the commercial fields in Maitland, surveys were conducted at randomized times between 5:00 and 10:30. Honeybee hives were maintained by apiarists in the commercial pumpkin fields.

Initially, surveys were performed along 50m transects to observe flower-visitors; however, we adjusted the surveys to focal individual flower observations given the uneven number of male and female cucurbit flowers (only few male flowers) produced within established transects at all site locations. Therefore, 10 male and 10 female flowers per cultivar per day were observed for 5 minutes each.

For each survey, when an insect was observed visiting a cucurbit flower, however, we adjusted the surveys to focal individual flower observations given the uneven number of male and female cucurbit flowers (only few males flowers) produced within established transects at all site locations. Therefore, 10 male and 10 female flowers per cultivar per day were observed for 5 minutes each.

For each survey, when an insect was observed visiting a cucurbit flower, we recorded insect identity, the number of visits to other flowers, and duration of visits (in seconds) to male and female flowers. As pollination is most likely to occur when insect visitors contact the reproductive structures of flowers, we further noted whether the insect contacted the reproductive parts or petals only of the cucurbit flowers. For this study, we only considered contact with flower reproductive parts as viable visits for identifying potential pollinators. Observations of the same individual insect spanned up to 10 flower visits, and each insect was observed for a maximum of 300 seconds. For each sampling event, observations were taken at random times to consider the variation in the diurnal activity of different insects. Surveys were undertaken on warm, and dry days without strong wind (< 3m/s). Unknown insects were collected following flower visits in ethanol for later identification. Insects were identified to species (for bees) or sorted into morphospecies and major groups (for flies).

Floral Strips

In addition to the cucurbit flower-visitor surveys described above, additional transect walks were conducted at the commercial field in the Newcastle-Maitland region to assess whether insect visitors of pumpkin and zucchini flowers also visited alternative floral resources. The floral strips included sunflower (*Helianthus annuus*), California poppy (*Eschscholzia californica*), calendula, brassica, borage (*Borago officinalis*), and sweet alyssum (*Lobularia maritima*).

In total, eight 50 m transects were established along cucurbit crop edges, and six 50 m transects were established within sown flower strips adjacent to commercial cucurbit fields. Cucurbit flower visitation was assessed by observing 10 male and 10 female flowers per cultivar per day for 5 minutes during anthesis across 5 sampling events in fields adjacent to flower strips. Flower strip visitation was assessed using 15-minute observations per transect, during which insect visitation (count of visits) to each plant type was recorded. These records allowed identification of the most attractive non-cucurbit plants for fly visitors.

All transects were conducted by walking slowly and in the direction of the sun to avoid casting shadows on flowers. To index floral abundance, male and female cucurbit flowers were counted along the first 10 m of each transect once per day immediately after observations.

Vegetables and Herbs

At the market gardens in the Maitland region, we established a minimum of three mixed patches (cucurbits plus co-flowering vegetables and herbs) to observe flower visitor behaviour to cucurbit flowers versus available floral resources. The co-flowering vegetables and herbs included tomato (*Solanum lycopersicum*), basil (*Ocimum basilicum*), spinach (*Spinacia oleracea*), eggplant (*Solanum melongena*), rosemary (*Salvia rosmarinus*), and chili (*Capsicum frutescens).*

For each survey, when an insect was first observed visiting a cucurbit flower, it was tracked for up to 5 minutes. Visit duration was recorded separately for male and female cucurbit flowers, as well as for co-flowering vegetables and herbs. Observations spanned 10 sampling events. Given the smaller size of these fields and associated cucurbit flower numbers, in each survey, six pairs of male and female flowers were observed for 5 minutes each.

Results and Discussion

Pollination Efficiency of Eristalinae Flies for Pumpkins and Zucchinis

Maitland Cage Trials - 2023

A total of 2450 pupae were released into the cages over multiple stockings (approximately 20 flies/m^2) and, on average, 70% of flies released into the cages hatched.

Across all cages, flies were observed visiting 97 male flowers and only 8 female flowers. However, from over 9 hours of observations, only 4 minutes involved flies actively foraging on male flowers. Flies were observed on female flowers for only 5 minutes with no evidence of foraging (Plate 4).

Out of 16 flowers tagged as controls (open to insect pollination) in the open field only three set fruit (18%) with an average harvest weight of 4.19kg. There was no fruit set by flies in the cages. Approximately 60% of flowers which were hand pollinated set fruit in the open field and cages and these averaged 2.92kg and 2.73kg respectively at harvest. Average of fruit weights were low as fruit were not fully mature at harvest, this was due to the crop being ploughed early due to the poor fruit set (Plate 5).

Plate 4: a) Karen Santos performing pollinator foraging activity scoring inside cages; b) Typical behaviour observed within cages of *E. tenax* on male flower petals. Images by Raylea Rowbottom

Plate 5: Pumpkin fruit development from a) control pollinated flower in the open field and b) supplementary (hand) pollinated flower inside cage 1. Images: Mark van Schilt

Maitland Trials - 2024

Five days of observations were conducted between 6th November and 14th November 2024 with an average of 4 individual sets of observations at different times each day. *E. tenax* was only observed on the reproductive organs of male flowers on 6 occasions throughout all of the surveys and was never observed visiting female flowers.

Over the duration of this experiment, we tagged 130 female flowers, half of which were controls (open pollinated) while the other half were hand pollinated. Within the cages, only 16 tagged flowers were recovered. Fifty percent of hand pollinated flowers set within the cages but none of the flowers tagged for fly only pollination set fruit. Within the open field, 15 tagged flowers were recovered. Only 3 flowers left for insect pollination set fruit (9%) whereas 12 of the hand pollinated flowers set fruit (36%). For both the open and cage hand pollinated fruit there was no difference in the average weight (2.86kg and 2.81kg respectively) (Plate 6).

Plate 6: Image showing fruit harvest comparisons between hand pollinations (orange tape) and controls (pink tape). Photo credit by Mark Van Schilt

Despite an estimated 6960 *E. punctulatus* hatching from open releases within the crop, none were observed foraging on the pumpkin crop over a total of 250m of transect surveys conducted across 8 days and 2 different time periods (morning 8-11am and midday 12-2pm).

Shadehouse Pollination Trial

Given the poor performance of flies at Maitland, we conducted pot trials under different environmental and growing conditions using three different pumpkin and zucchini varieties in Tasmania to determine whether poor fly performance was likely due to environmental conditions, or a fundamental incompatibility between both fly species and cucurbit variety used in the field trial. Over all observation periods within the trial, only 2 male flowers were visited across all 3 varieties and there was no visitation to female flowers. The numbers of male and female flowers visible in each observation period ranged from 1 to 9 and 2 to 3 respectively. Average fly numbers during observations were 37 individuals per cage, with *E. tenax* ranging between 46-55 individuals and *E. punctulatus* between 4-39 individuals. A pronounced decline in fly numbers was observed over the five-day period, and by day five, very few flies remained alive within cages. No fruit set was recorded in any treatment.

Collectively, the cage trials, shadehouse trials, wild pollinator surveys and open field release of Eristalinae flies undertaken in this study suggest that the prospects of pollinating either pumpkins or zucchinis (both Cucurbita species) with *Eristalis teanx* or *Eristalinus punctulatus* are poor. Furthermore, wild pollinator surveys of these crops in Maitland and Hawkesbury indicate wild fly pollinator visitor diversity is low for these crops. Although, at the time this work was undertaken, a concurrent study conducted by UNE and seedPurity found that *E. tenax* was however a capable and highly effective pollinator of melons (Citrullus and Cucumis species). This suggests that the suitability of Eristalini flies, or potentially flies more generally, to pollinate cucurbits may be specific to crop type (genus).

Pollinator Surveys - Cucurbits
Zucchini Flowers

Zucchini flowers received a total of 1,380 recorded insect visits across five sampling months in 2024. Early-season (February/April) market gardens accounted for 227 observations across 3 sites, while late-season (October-December) commercial farms accounted for 1,153 observations across nine sites cultivating 'Rosa', 'Eva', 'Nitro', and 'Goldie' zucchini varieties. Across 43 sampling days, there were 9 female flowers and 8 eight male flowers blooming on average per day within an observation area.

Across all farms and sampling periods, where similar numbers of male and female zucchini flowers were observed simultaneously, female flowers received 950 insect visits (69%), compared to 430 visits to male flowers (31%), suggesting female flowers were more attractive to insects than male flowers. The most abundant floral visitors of zucchini were honeybees, ants, and pumpkin beetles (Table 1).

Table 1: Identity of insects observed visiting zucchini flowers within three non-commercial field sites and nine commercial farms (Sydney and Maitland, New South Wales) in February - April, October - December 2024.

Insect group	***Order***	***Family***	***Common name***
Honeybees	Hymenoptera	Apidae	European honeybee
Ants	Hymenoptera	Formicidae	Ants
Pumpkin beetles	Coleoptera	Chrysomelidae	Pumpkin beetles
Other flies	Diptera		Flies
Native bees	Hymenoptera	Halictidae	Sweat bees
Fruit flies	Diptera	Tephritidae	Fruit flies
Lady beetles	Coleoptera	Coccinellidae	28-spotted lady beetle, Hadda beetle
Hover flies	Diptera	Syrphidae	Hover flies
Lady beetles	Coleoptera	Coccinellidae	Lady beetles
True bugs	Hemiptera		True bugs
Butterflies	Lepidoptera	Pieridae	Cabbage white butterfly
Native bees	Hymenoptera	Apidae	Blue-banded bee
Wasps	Hymenoptera	Ichnuemonidae	Parasitic wasps
Long-legged flies	Diptera	Dolicopodidae	Long-legged flies
Other beetles	Coleoptera		Beetles
Hover flies	Diptera	Syrphidae	European drone fly
Non-native bees	Hymenoptera	Megachilidae	African carder bee

Insect visitation patterns differed markedly between non-commercial sites and commercial farming systems and thus sampling periods. During early-season sampling at non-commercial sites, zucchini flowers were strongly dominated by ant visits (Figure 2). In February, female flowers were visited exclusively by ants (100% of visits), while male flowers were also ant-dominated (69%). Lady beetles were also common visitors of male zucchini flowers only in February; however, the common species present was the 28-spotted lady beetle, which also consumes cucurbit pollen. This pattern persisted in April, with ants accounting for 68% of visits to female flowers and 100% of visits to male flowers. No honeybees visited zucchini flowers in February and April (non-commercial sites).

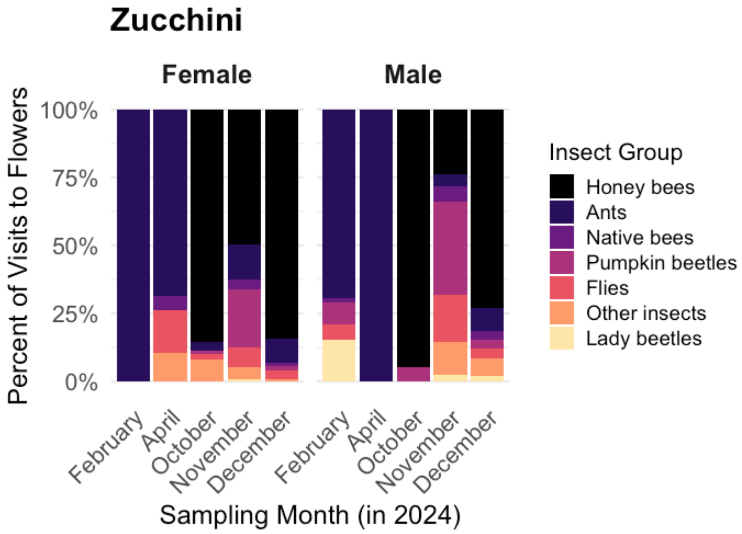

Figure 2: Proportional composition of insect visitor groups to male and female zucchini flowers across five sampling months in 2024. Early-season surveys (February, April) were performed across three non-commercial sites (Maitland, New South Wales) and later-season surveys (October-December) were performed across nine commercial farm sites (Maitland and Sydney, New South Wales). Bars represent the percentage of total visits within each month and flower sex (male, female). Insect groups are shown by different colours.

In contrast, surveys conducted at commercial farms during October-December showed a shift toward honeybees as the most dominant floral visitors of zucchini flowers (Figure 4 above). In October, honeybees comprised 86% of visits to female flowers and 95% of visits to male flowers. In November, honeybees remained the most frequent visitors to female flowers (50% of visits); however, reduced visitation by honeybees was observed the same month in male flowers, with pumpkin beetles, common pests of cucurbit, representing the most abundant group (34% of visits). This shift may reflect changes in floral resource availability (pollen), pollinator density, or pest population dynamics during peak flowering, given that pumpkin beetles feed on pollen and honeybees visit male flowers to collect pollen. Honeybees then returned as the dominant visitor group of commercial zucchini flowers in December (84% of female visits; 73% of male visits).

Pumpkin Flowers

Pumpkin flowers received a total of 674 recorded insect visits across four sampling months in 2024. Early-season (February/April) non-commercial farms accounted for 337 observations across two sites, while later-season (November/December) commercial farms accounted for 338 observations across four sites and cultivated 'Butternut' and 'Sampson' pumpkin cultivars. Across 38 sampling days, there were approximately eight female flowers and ten male flowers blooming on average each day per observation area.

In February/April, male pumpkin flowers received 258 visits (77%), compared to 79 visits to female flowers (23%); however, in November/December, male flowers received 110 visits (33%), compared to 228 visits to female flowers (67%). This shift in visitation between flower sexes across production periods may reflect seasonal differences in floral resource availability or changes in visitor assemblage compositions. The most abundant floral visitors of pumpkin were honeybees, ants, and pumpkin beetles (Table 2).

Table 2: Insects observed visiting pumpkin flowers within non-commercial field sites and commercial farms (Sydney and Maitland, New South Wales) in February, April, November, and December 2024.

Insect group	***Order***	***Family***	***Common name***
Honeybees	Hymenoptera	Apidae	European honeybee
Ants	Hymenoptera	Formicidae	Ants
Pumpkin beetles	Coleoptera	Chrysomelidae	Pumpkin beetles
Other flies	Diptera		Flies
Lady beetles	Coleoptera	Coccinellidae	28-spotted lady beetle, Hadda beetle
Native bees	Hymenoptera	Apidae	Blue-banded bees
Fruit flies	Diptera	Tephritidae	Fruit flies
True bugs	Hemiptera		True bugs
Native bees	Hymenoptera	Halictidae	Sweat bees
Native bees	Hymenoptera	Apidae	Stingless bees
Butterflies	Lepidoptera		Butterflies or moths
Hover flies	Diptera	Syrphidae	Hover flies
Lady beetles	Coleoptera	Coccinellidae	Lady beetles
Native bees	Hymenoptera	Apidae	Green carpenter bee
Other beetles	Coleoptera		Beetles
Long-legged flies	Diptera	Dolicopodidae	Long-legged flies
Native bees	Hymenoptera	Halictidae	Sweat bees

The most abundance pumpkin floral visitors varied by month and flower sex. In February (n = 150), honeybees were the most frequent visitors to female flowers (50% of visits), while native bees were the most frequent visitors to male flowers (28.3%), reflecting relatively mixed assemblages during early-season sampling (Figure 3). In April (n = 187), ants dominated visitation to female flowers (77.6%), whereas honeybees were the most frequent visitors to male flowers (46.4%).

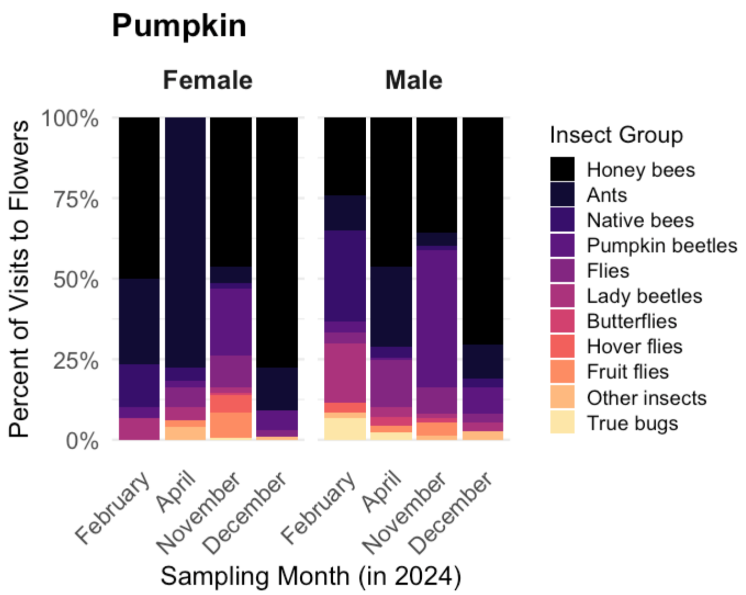

Figure 3: Proportional composition of insect visitor groups to male and female pumpkin flowers across four sampling months in 2024. Early-season surveys (February, April) were performed across two non-commercial farm sites (Maitland, New South Wales) and later-season surveys (November, December) were performed across four commercial farm sites (Maitland and Sydney, New South Wales). Bars represent the percentage of total visits within each month and flower sex (male, female). Insect groups are shown by different colours.

During later-season commercial sampling, honeybees were consistently the most frequent visitors of pumpkin flowers. In November (n = 203), honeybees were the most frequent visitors to female flowers (46.2%), while pumpkin beetles were the most frequent visitors to male flowers (42.5%; (Figure 5), which was the same pattern observed in zucchini. In December (n = 136), honeybees dominated visitation to both female (77.6%) and male flowers (70.3%).

Cucumber Flowers

Cucumber flowers received a total of 467 recorded insect visits across three non-commercial sites in February and April of 2024. Across 13 sampling days, there were approximately four female flowers and 23 male flowers blooming on average each day per observation area. Across all farms and sampling periods, male cucumber flowers received 419 visits (90%), while female flowers received only 48 visits (10%), even though both male and female flowers were observed at the same time during observational surveys. This suggests that male cucumber flowers were significantly more attractive to insect floral visitors. The most abundant floral visitors of cucumber were ants, stingless bees, and blue-banded bees (Table 3).

Table 3: Insects observed visiting cucumber flowers within non-commercial field sites (Maitland, New South Wales) in February and April 2024.

Insect group	***Order***	***Family***	***Common name***
Ants	Hymenoptera	Formicidae	Ants
Native bees	Hymenoptera	Apidae	Stingless bees
Native bees	Hymenoptera	Apidae	Blue-banded bees
Other flies	Diptera		Flies
Native bees	Hymenoptera	Halictidae	Sweat bees
Butterflies	Lepidoptera	Pieridae	Cabbage white butterfly
Lady beetles	Coleoptera	Coccinellidae	28-spotted lady beetle, Hadda beetle
Native bees	Hymenoptera	Megachilidae	Leaf-cutter bees
Butterflies	Lepidoptera		Butterflies
Lady beetles	Coleoptera	Coccinellidae	Lady beetles
Native bees	Hymenoptera	Halictidae	Sweat bees
Hover flies	Diptera	Syrphidae	Hover flies
Bee flies	Diptera	Bombylidae	Bee flies
Hover flies	Diptera	Syrphidae	Hover flies
Moths	Lepidoptera		Butterflies or moths
Native bees	Hymenoptera	Apidae	Green carpenter bee
Pumpkin beetles	Coleoptera	Chrysomelidae	Pumpkin beetles
Blow flies	Diptera	Calliphoridae	Blow flies

Cucumber flowers were surveyed during early-season (February and April) non-commercial production. In February (n = 427), native bees were the most frequent visitors to both female (37.5% of visits) and male flowers (56.8%; Figure 4). In April (n = 40), ants were the most frequent visitors to female flowers (62.5%) and dominated visitation to male flowers (75%). Zero honeybees were observed visiting cucumber flowers across all sampling dates.

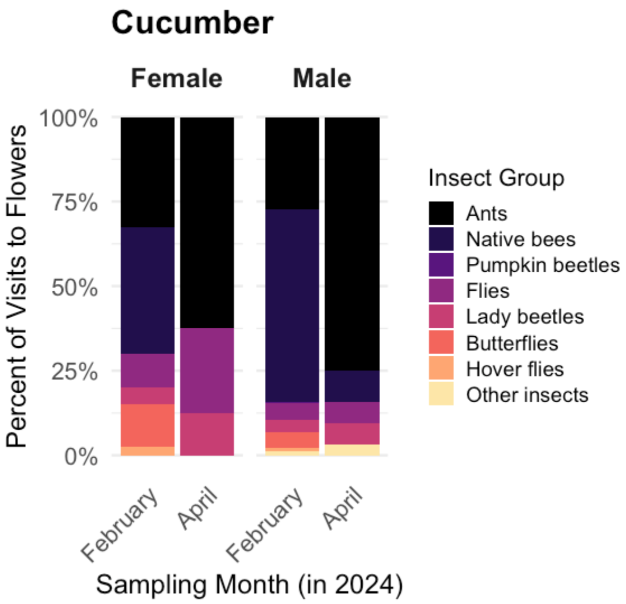

Figure 4: Proportional composition of insect visitor groups to male and female cucumber flowers across two sampling months in 2024. Surveys were performed across three non-commercial farm sites (Maitland, New South Wales). Bars represent the percentage of total visits within each month and flower sex (male, female). Insect groups are shown by different colours.

Melon Flowers

Melon flowers received a total of 118 recorded insect visits at one non-commercial site in February 2024. Across four sampling days, there were approximately two female flowers and four male flowers blooming on average each day within an observation area. In total, male flowers received 103 visits (13%), while female flowers received only 15 visits (87%). The most abundant floral visitors of cucumber were ants, other flies, and sweat bees. All insect floral visitors of cucumber can be found in Table 4.

Table 4: Insects observed visiting melon flowers within a non-commercial field site (Maitland, New South Wales) in February 2024.

Insect group	***Order***	***Family***	***Common name***
Ants	Hymenoptera	Formicidae	Ants
Other flies	Diptera		Flies
Native bees	Hymenoptera	Halictidae	Sweat bees
Native bees	Hymenoptera	Apidae	Stingless bees
Honeybees	Hymenoptera	Apidae	European honeybee
Native bees	Hymenoptera	Apidae	Blue-banded bees
Butterflies	Lepidoptera	Pieridae	Cabbage white butterfly
Hover flies	Diptera	Syrphidae	Hover flies
Lady beetles	Coleoptera	Coccinellidae	28-spotted lady beetle, Hadda beetle

Across the 118 total visits, ants were the most frequent visitors to female melon flowers (60% of visits) and to male flowers (54%). Hover flies only visited female melon flowers, while lady beetles and butterflies only visited male flowers; however, all groups visited in relatively low numbers (Figure 5).

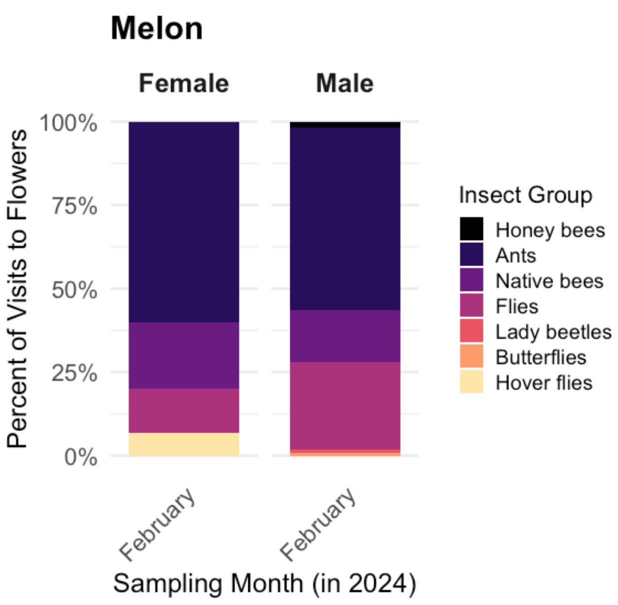

Figure 5: Proportional composition of insect visitor groups to male and female melon flowers in February 2024. Surveys were performed at one non-commercial farm site (Maitland, New South Wales). Bars represent the percentage of total visits within each month and flower sex (male, female). Insect groups are shown by different colours.

Insect Visitation to Mouse Melon Flowers

Mouse melon flowers received a total of 160 recorded insect visits across two non-commercial sites in April of 2024. Across six sampling days, there were approximately 40 female flowers and 57 male flowers blooming on average each day per observation area. In total, male flowers received 96 visits (60%), while female flowers received 64 visits (40%). The most abundant floral visitors of mouse melon were leaf-cutter bees, butterflies, and blue-banded bees (Table 5).

Table 5: Insects observed visiting mouse melon flowers within a non-commercial field site (Maitland, New South Wales) in February 2024.

Insect group	***Order***	***Family***	***Common name***
Native bees	Hymenoptera	Megachilidae	Leaf-cutter bees
Butterflies	Lepidoptera		Butterflies
Native bees	Hymenoptera	Apidae	Blue-banded bees
Native bees	Hymenoptera	Halictidae	Sweat bees
Other flies	Diptera		Flies
Ants	Hymenoptera	Formicidae	Ants
Butterflies	Lepidoptera	Pieridae	Cabbage white butterfly
Honeybees	Hymenoptera	Apidae	European honeybee
Native bees	Hymenoptera	Halictidae	Sweat bees

Across the 160 total visits, native bees were the most frequent visitors to female mouse melon flowers (38% of visits) and to male flowers (56%; Figure 8). Honeybees were only observed on male flowers (Figure 6).

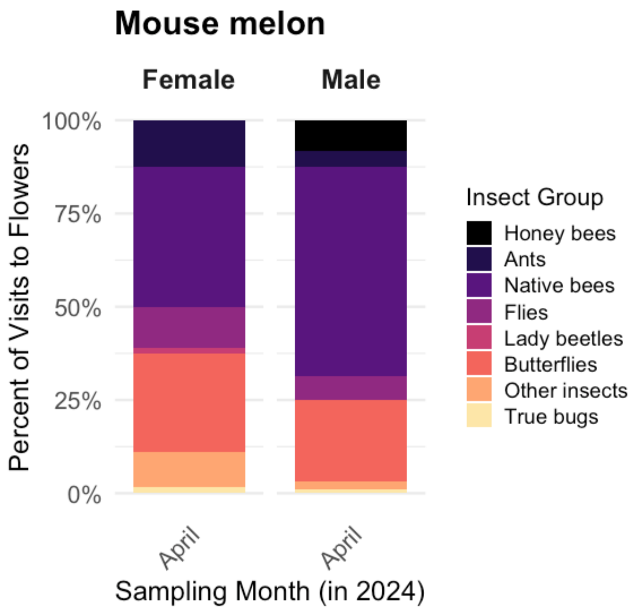

Figure 6: Proportional composition of insect visitor groups to male and female mouse melon flowers in April 2024. Surveys were performed across two non-commercial farm sites (Maitland, New South Wales). Bars represent the percentage of total visits within each month and flower sex (male, female). Insect groups are shown by different colours.

Floral Strips

A total of 816 flower-visitor observations were recorded across the study period under average conditions of 24 °C and 61% relative humidity. Floral strip plantings supported a diverse assemblage of insects (Figure 7). Of the 13 insect groups recorded, 11 were observed visiting both cucurbit crops and floral strip plants, indicating overlap in resource use between crop and non-crop floral resources. Only rhinid flies and blow flies were recorded exclusively on co-flowering plants. Sunflower and brassica were particularly important floral strip species, supporting a broad range of insect visitors.

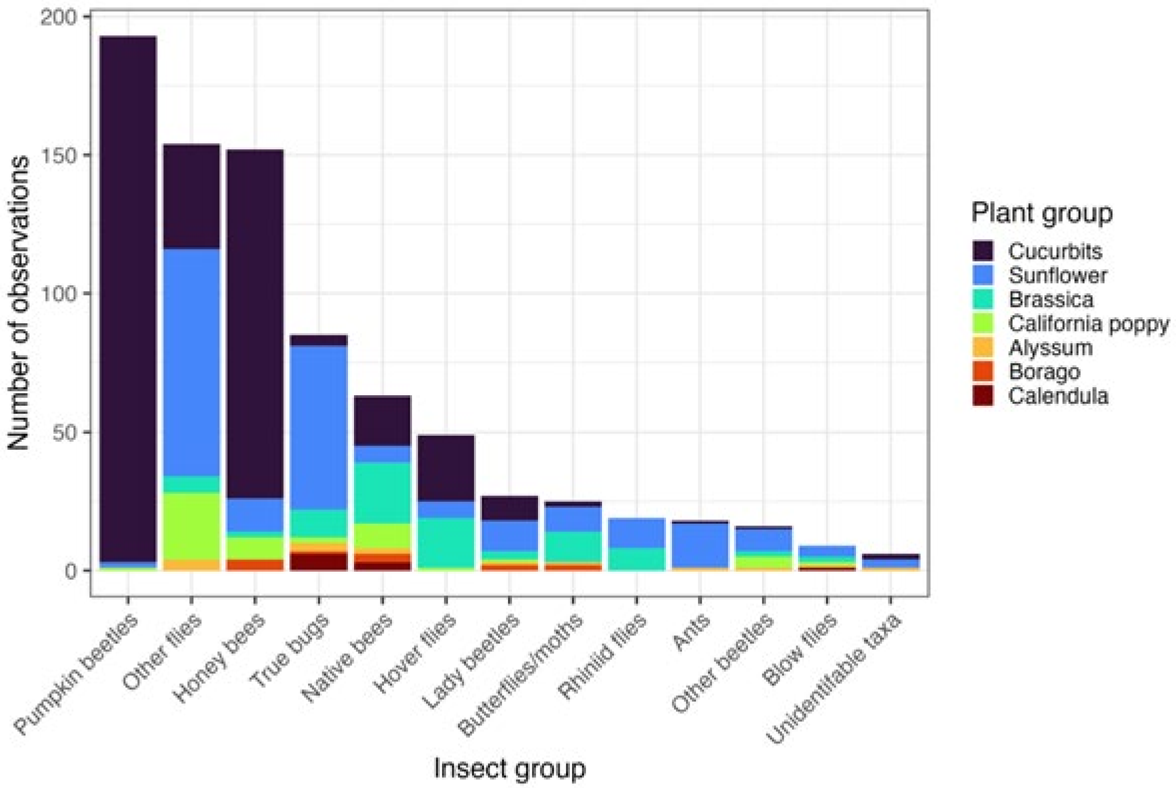

Figure 7: Number of insect observations recorded in a commercial cucurbit system. Insect visitors were grouped into broad taxonomic categories and observations are shown for cucurbits (pumpkin and zucchini combined) and six co-flowering plant species. Insect taxa were grouped into major taxonomic categories. Bar colours indicate the plant group on which each insect group was observed.

Several taxa that visited cucurbit flowers also visited other floral strip plant species. This means floral strips supported a range of beneficial insects that may provide additional ecosystem services. These include nutrient cycling (e.g. blow flies) and biological pest control (e.g. hover fly larvae and predatory flies). These results indicate that floral strips can increase overall insect diversity within cropping systems and support beneficial insect groups beyond pollinators. While direct contributions to cucurbit pollination varied among plant species, the inclusion of floral strips is likely to enhance broader ecosystem functioning, with potential indirect benefits for crop production.

While many of the insects recorded were pollinators or beneficial insects, pumpkin beetles were also abundant throughout the study and were observed predominantly on cucurbit crops. This reinforces the need for integrated management approaches that support beneficial insects while continuing to monitor and manage key crop pests.

Vegetables and Herbs

Over 5,000 flower-visitor observations were recorded across the study period, with 15 distinct insect groups observed visiting cucurbit crops and co-flowering vegetables and herbs. Many key pollinator groups, including blue-banded bees, stingless bees, sweat bees, leaf-cutter bees and honeybees, were observed visiting both cucurbit flowers and co-flowering plants (Figure 8). Co-flowering plants received more insect visits than cucurbit flowers during standardised observation periods, indicating that some non-crop plants may be more attractive floral resources. Honeybees, stingless bees, and blue-banded bees were frequently observed on co-flowering basil and regularly visited cucurbit flowers (Figure 8), indicating strong overlap in resource use between specific herb and crop species. These observations suggest that carefully selected flowering herbs and vegetables may help maintain pollinator populations within production systems.

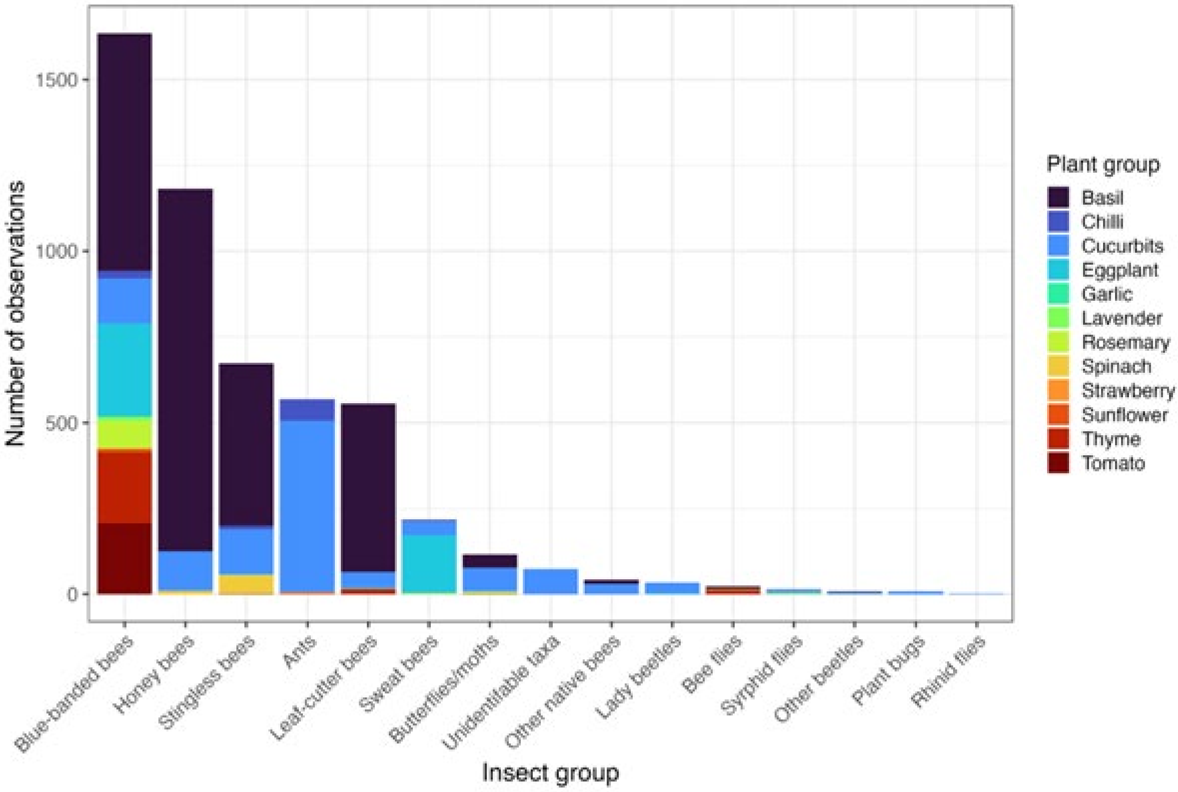

Figure 8: Number of insect observations recorded on different plant groups. Plant groups including co-flowering plants (basil, chili, eggplant, garlic, lavender, rosemary, spinach, strawberry, sunflower, thyme, and tomato) as well as cucurbit plants including (zucchini, pumpkin, cucumber, mouse melon, and melon). Insect taxa were grouped into major taxonomic categories. Bar colours indicate the plant group on which each insect group was observed.

The proportion of visits involving reproductive contact varied across cucurbit crops, flower sexes, and insect groups. Cucumber, melon, and mouse melon exhibited consistently high levels of reproductive contact across both male and female flowers. In cucumber, reproductive contact occurred in 87.5% of insect visits to female flowers and 95.9% of visits to male flowers. Similarly high contact rates were observed in melon (100% in female flowers; 96.1% in male flowers) and mouse melon (96.9% in female flowers; 97.9% in male flowers). These results indicate that the majority of insect visits to these crops involved contact with reproductive structures and were therefore possible to contribute to effective pollination.

High reproductive contact in cucurbit crops was also consistent across multiple insect groups. In cucumber, butterflies and native bees contacted reproductive structures in all recorded visits (100%), while ants (94%), lady beetles (85%), and flies (81%) also showed high contact rates. Comparable patterns were observed in melon and mouse melon, where native bees, ants, and butterflies frequently contacted reproductive structures in nearly all visits.

In contrast, pumpkin and zucchini showed more variable patterns of reproductive contact by insect floral visitors. In pumpkin, reproductive contact occurred in 66.8% of visits to female flowers and 63.9% of visits to male flowers, with approximately one-third of visits involving only petal contact. While honeybees (94%) and native bees (88%) maintained high reproductive contact, non-bee taxa were substantially less likely to contact reproductive structures. Pumpkin beetles contacted reproductive structures in only 4% of visits, and flies (including hover flies and fruit flies) exhibited reproductive contact in less than 12% of visits.

Zucchini showed a similar but more pronounced pattern. Reproductive contact was relatively high in female flowers (80.1%) but much lower in male flowers (49.8%), where approximately half of visits involved only petal contact. Honeybees (90%) and ants (88%) maintained high reproductive contact, whereas pumpkin beetles (16%), flies (20%), fruit flies (29%), and hover flies (7%) showed low probabilities of contacting reproductive structures.

Overall, these findings demonstrate that insect mediated pollination varied substantially among cucurbit crops and insect groups. Cucumber, melon, and mouse melon showed consistently high behavioural evidence of pollen transfer, while pumpkin, and particularly zucchini, exhibited greater variability and lower probabilities of effective pollination from several non-bee taxa.

Furthermore, these results demonstrate that co-flowering vegetables and herbs can support a wide range of insect groups within cucurbit production systems. However, the extent to which these plants contribute to crop pollination varies among taxa, with some insect groups providing direct pollination services and others contributing more indirectly through their presence and movement within the system.

Rubus Trials (Blackberry and Raspberry)

The work reported in this section builds on prior research conducted under the Hort Innovation project "*Managing flies for crop pollination"* (PH16002), which established the foundation for the use of managed flies as crop pollinators. PH16002 demonstrated that the hoverfly *Eristalis tenax* was an effective pollinator of Rubus. The current project represents progression from these small-scale controlled assessments to larger enclosed polytunnels trials and open release trials to advance development of managed *E. tenax* towards integration into commercial Rubus production systems. In PH16002, we demonstrated that *E. tenax* has significant potential as a cool season pollinator, and this is potentially when current pollination systems are most limiting for Rubus production. For this reason, our research in the current project focused principally on winter and spring flowering crops.

Methods

All trials were conducted across four commercial farms, three in the Mid North Coast region of New South Wales (30.3° S, 153.1° E) and one in Dunorlan, Tasmania (41.5°S, 146.6°E) to evaluate the pollination performance of managed fly pollinators under different climates.

In the Mid North Coast region of New South Wales, blackberry trials were conducted on the 'Elvira' blackberry cultivar across two commercial sites in enclosed polytunnels during spring (September–November 2023) and on one site during winter (May–July 2024). A single trial was conducted on Raspberry (cultivar: 'Maravilla') during spring (September–October 2024). Pollinator research in this project concluded with an open release blackberry pollination trial conducted on the 'Victoria' cultivar in Tasmania during Spring, 2025. In this trial we assessed deployment strategies, dispersal patterns and retention of flies released.

For the Mid North Coast region of New South Wales, typical average spring temperatures range between 11.9 – 24.9°C with an average monthly rainfall of 87.8mm whereas in winter temperatures ranging from 6.4-20.2°C with average monthly rainfall of 107.1mm. In Dunorlan, Tasmania, spring temperatures average between 4.3 and 15.5°C with 79mm average monthly rainfall (Figure 9).

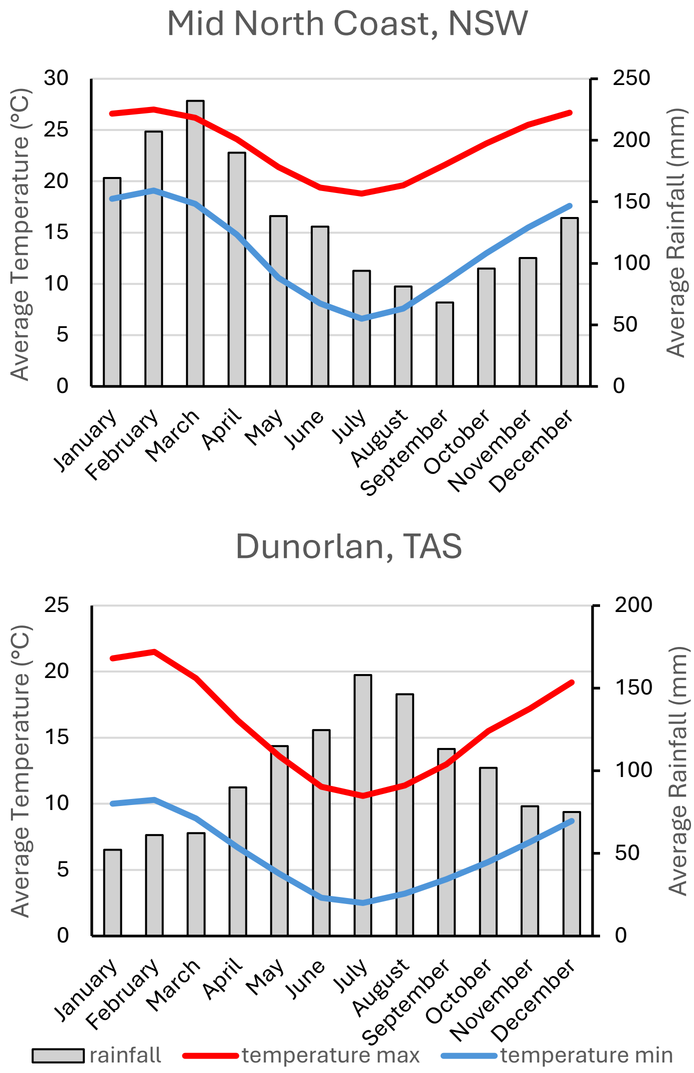

Figure 7: Average maximum and minimum temperature (°C) and rainfall (mm) for the Mid North Coast region and Northern Tasmania.

Enclosed polytunnel trials

All trials were designed to compare pollination under protected cropping conditions *E. tenax* against the commercial standard of pollination predominantly by stocked European honeybees (*Apis* mellifera, 4 hives/ha) with varying levels of contribution from wild pollinators (native bees, syrphid hoverflies and ants). *Eristalis tenax* was stocked into individual enclosed polytunnels, approximately 693m^2 in area (77m x 9m) and containing 252 plants across 3 rows. In each trial, fruit set within the hoverfly pollinated tunnel was compared with open-pollinated fruit from an adjacent, open polytunnel of the same size.

To contain *E. tenax*, we enclosed both ends of one polytunnel with 5mm cross-woven aperture netting (Plate 7). This also prevented the entry of other pollinators from the open system into the hoverfly pollination treatment, while allowing sufficient air circulation within the enclosed tunnel to minimise disease pressure. Although small wild insects (<5 mm) could enter or exit the enclosure, their presence was minimal and unlikely to influence yields. Environmental data loggers (temperature, humidity and light) were placed at set locations within the open and enclosed polytunnels to monitor climatic conditions across the two pollination treatments.

Plate 7: Mid North Coast NSW example of an enclosed polytunnel used for trials and stocked with *Eristalis tenax*. Image credit: Dr Raylea Rowbottom.

Managed *E. tenax* were introduced mostly as pupae in a series of staged deployments (Table 6). Pupae placed inside deployment boxes located at either end of the enclosed polytunnel typically emerged as adults over a 7-to-10-day period. The total number and timing of deployments during the trial depended on crop stage and flowering rates.

Table 6: Crop type, season and releases of *E. tenax* (dates, quantity and estimated number of flies/plant based of an 80% observed average hatching rate across trials) in Rubus polytunnels. Spring data includes both site 1 and site 2 releases of *E. tenax.*

Crop	***Season***	***Date***	***Released Pupae***	***Flies/plant***
Blackberry	Spring (Site 1)	13-Sep-23	6,000	68
		22-Sep-23	15,304	
	Spring (Site 2)	22-Sep-23	4,825	52
		29-Sep-23	8,000	
	Winter	31-May-24	500	24
		13-Jun-24	750	
		26-Jun-24	1,000	
		4-Jul-24	1,400	
		16-Jul-24	3,800	
Raspberry	Spring	26-Aug-24	6,500	51
		9-Sept-24	4,500	
		23-Sept-24	6,000	
		7-Oct-24	5,000	
		21-Oct-24	5,000	

Spot counts of pollinators (number of insects foraging flowers) were undertaken repeatedly throughout the flowering period along 33 transects distributed within the enclosed and open tunnels (Figure 10), with observations made once to three times daily to capture diurnal patterns in pollinator activity. In spring, surveys were completed between morning (08:00–10:00), midday (12:00–14:00), and afternoon (15:00–17:00). In winter, surveys were completed between 09:00–10:30 (morning), 11:30–13:00 (midday), and 14:00–15:30 (afternoon), following the same methodology as the spring transects. Differences in survey timing between seasons reflect colder morning temperatures and weather constraints in winter that delayed pollinator activity. A total of 46 pollinator surveys (1,380 transects) were conducted within the springtime blackberry trials and 26 surveys (780 transects) were conducted in the winter trial.

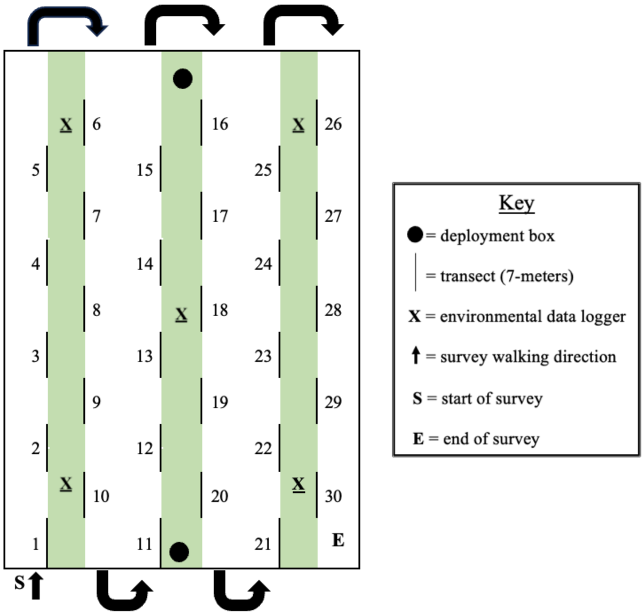

Figure 8: Schematic design of polytunnel transect set up used to assess pollinator activity patterns in both blackberry and raspberry Rubus crops. The green rows represent rows of Rubus production within a polytunnel system in which foraging activity scores were conducted on both sides of each row.

To compare hoverfly and open-pollination, three pollination treatments were applied weekly in both the enclosed and open tunnels: (i) hand-, (ii) self-, and (iii) open-pollination. The hand pollination treatment was included to provide an indication of fruit weight achievable when pollination was unlimiting. It was conducted by brushing dehisced anthers over receptive stigmas of tagged isolated (bagged) flowers using pollen sourced from separately isolated flowers. Hand-pollinated flowers were then re-bagged with insect-proof netting until the stigmas became unreceptive (typically after three to five days). Within the self-pollination treatments, flowers were individually bagged for the duration of floral receptivity to exclude insect visitation. The insect-proof bags were removed from the hand and self-pollination treatments once stigmas became unreceptive to prevent mold development on ripening fruit. Within each tunnel, an additional set of flowers were tagged when their stigmas became receptive and left open for insect pollination either by flies within the enclosed tunnel, or honeybees and other wild pollinators in the open tunnels (open pollination treatment).

In each experiment, flower buds were tagged at balloon stage and allocated to the different pollination treatments at weekly intervals so that the effects of the two pollination systems (fly vs open) and the effect of differences in fly stocking rate could be tracked through time. Tagged buds were randomly selected within each crop row to account for variation in microclimatic conditions and pollinator activity. At each time, 50 (winter trial) to 100 (spring trials) buds were allocated to the open pollinated treatment and an additional 10 buds were allocated to the hand and self-pollination treatments. Tagged fruits were harvested at commercial ripeness and weighed.

Fruit quality was assessed according to commercial industry grading standards. Fruits without defects were classified as marketable. Fruits exhibiting critical defects (e.g. fungal infection, pest damage), progressive defects (e.g. damaged drupelets), or stable defects (e.g. environmental damage such as rubbing, wind injury, white drupelet disorder, or red drupelet disorder) were classified as unmarketable. Only fruits free from pest damage, fungal infection, and damaged drupelets were included in weight analyses, while all fruits were retained for overall quality assessments.

Optimisation of fly deployment strategies and integration into commercial systems

E. tenax stocking (timing and number of releases), pesticide usage and adult fly foraging activity data were collated across all NSW tunnel trials and Tasmanian trials at the Dunorlan site including an earlier tunnel trial (2022), a pilot open release trial (2023) and a larger scale open release trial (2025 – see below) to compare the impact of different release strategies and crop management practices on fly abundance through the flowering period. Observations on the impact of pesticide usage on fly populations from these studies were supported with laboratory-based assays of oral and contact toxicity of some common pesticides to adult *E. tenax.* Laboratory trial methods were based on those reported by (Nagloo et al 2023 and Stanley and Preetha 2016). Each product was tested at concentrations equivalent to full, quarter and one sixteenth label rates by dilution of the product in deionized water (direct and indirect contact assays) or 20% sucrose solution (oral assays). Direct contact assays involved pipetting of a 10µl aliquot directly onto the thoracic region of each fly. Indirect assays were performed for each product/rate treatment by lining the base of the holding cages with an inert substrate mat that had been over sprayed with the corresponding treatment using a gas pressurised trial boom operating at 3 bars fitted with Teejet AIXR110015 nozzles delivering a 200L/ha equivalent water rate as coarse grade droplets. The treated mats and corresponding sample of flies were added to the holding cages within 5 minutes of spraying of the mats, before the spray had dried. Oral assays were performed by suspending the product in sucrose solution that was fed to the flies *ad-libitum* over a 24 hour period. All flies used in the trial were raised in the seedPurity insectary using a standardized rearing protocol. During the experiment, flies were held at 22^{o}C and 55%RH under 6500k LED light bars set to a 16hr light/8hr dark cycle and delivering an average of 4300 lux to the interior of the cages. Each treatment replicate comprised of 100 flies (approximately 1 day old from eclosion) held in a 30cm x 30cm x 30cm cage, with 4 replicates per treatment. Mortality rates were assessed every 30 min over a 6hr period then daily for 3 days and were standardized against corresponding control (untreated) flies of the same age, held under the same conditions.

Open Release Trials

Following a preliminary open release trial in 2023, we conducted a larger scale, semi-commercial open release at the Dunorlan site in November, 2025. The trial area comprised 1.7ha of tunnels organized in 5 blocks (Plate 8). Flies were deployed as pupae at the central point of each tunnel in blocks 606 and 608 at approximately weekly intervals for 3 weeks, starting on the 24th of November. The block was also stocked with honeybees (2.5 hives/ha). Surveys of pollinator activity were made along evenly spaced 6m long transects located in the central row of plants in each tunnel in blocks 605 to 606 9 (33 tunnels, 147 transects) on 8 days between the 24th of November and the 22nd of December. Each survey comprised spot counts of actively foraging honeybees and *E. tenax* in contact with blackberry flowers and a separate count of *E. tenax* observed flying or resting on foliage along each transect. Hatching rates of the pupae deployed in the trial were also assessed on each survey day. Details of commercial pesticide applications in the trial block during the survey period were sourced from the grower.

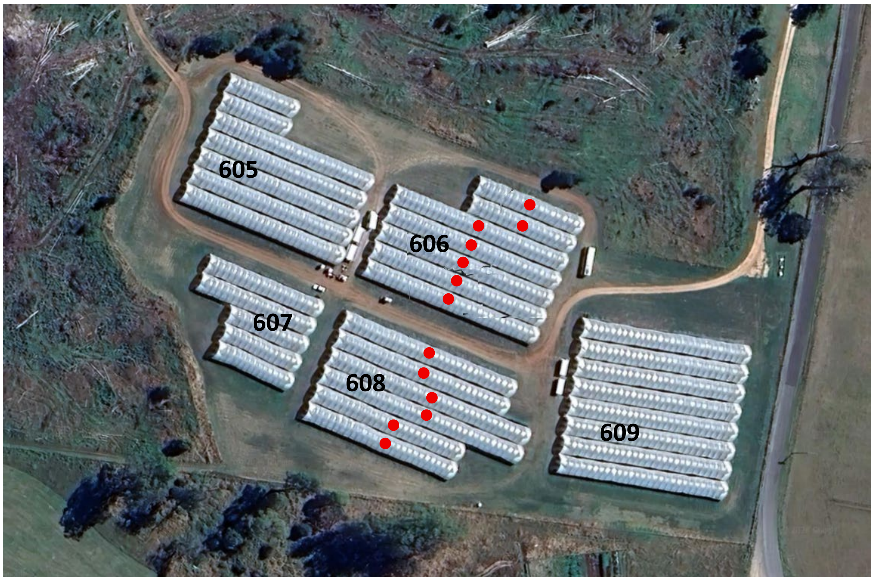

Plate 8: Layout if the site used for the 2025 open release blackberry pollination trial at Dunorlan, Tasmania. Flies were deployed as pupae in the centre of each tunnel located in blocks 606 and 608 (●). Spot count surveys of pollinator activity were performed in all tunnels (blocks 605 to 609).

Promotion of Wild Fly Pollinator Populations through Habitat Modifications

Artificial habitat units ("ponds") were established at Site 1 on the NSW mid-north coast in 2024 to assess whether wild Eristalinae flies could be attracted to, and reproduce within, supplemented habitat in commercial berry systems. Two treatments were implemented: 1) water-only ponds (control), and 2) plant-substrate ponds, containing decomposing blackberry leaves and stems to provide suitable substrates for fly oviposition and larval development.

Ponds were installed along farm margins to minimise interference with farm operations and were maintained under field conditions for approximately six weeks during spring (September–October), 2024. The ponds were constructed using low-cost, readily available materials (water, decomposing crop residues, and commercially available polyethylene containers), ensuring the approach reflects a practical and scalable on-farm intervention. Monitoring focused on the presence and development of Eristalinae flies, including egg laying, larval development, and pupation within artificial habitats. In addition, the presence of other invertebrates within the ponds was also monitored. Observations were conducted at regular intervals (every three to four days) to track insect use of the habitat resources over time (Plate 9).

Water-only ponds were removed partway through the trial (on day 31) as no Eristalinae flies utilised this treatment. In contrast, plant-substrate treatment ponds were retained for the full duration of the trial (43 days) as they supported fly larval development through to pupation. At the conclusion of the trial (day 31 for water-only and day 43 for plant-substrate ponds), all visible invertebrates were collected from each pond and identified to the lowest possible taxonomic grouping. Throughout the trial, fly larvae and pupae were collected, reared to adulthood, and identified to species-level to determine which fly species developed within the ponds.

Plate 9: Artificial habitat units “ponds” installed at site 1 on the NSW mid-north Coast with Jelena Preradovic checking for eggs and b) A female *E. tenax* ovipositing eggs amongst the leaf litter in one of the ponds. Image credit Dr. Abby Davis.

Results and Discussion

Blackberries

Foraging Activity in Enclosed Polytunnel Trials

Eristalis tenax was generally more abundant than *Apis mellifera* in surveys of pollinator foraging activity through all sampling periods (morning, mid-day and afternoon - Figure 11). On average, both species reached peak activity at midday, but *E. tenax* also remained active during cooler morning and late-afternoon periods. In spring, *E. tenax* was most abundant on blackberry flowers at temperatures between 22 and 30°C and at relative humidities between 40 and 60% (Figure 12). In contrast, *A. mellifera* was most abundant at higher temperatures (28–34°C) and lower relative humidity (<40%). In winter, overall pollinator activity was reduced (Figure 11) due to the lower temperatures, reduced bloom density and smaller individual deployments of pupae as the flowering period was longer and less intense. Environmental conditions within polytunnels did not differ between fly and open systems for spring or winter.

The complementary foraging patterns observed for *E. tenax* and *A. mellifera* suggest that combined stocking of both species could extend the effective daily pollination window when honeybee activity is reduced and improve consistency of pollination across cooler periods and variable environmental conditions typically experienced in early season production.

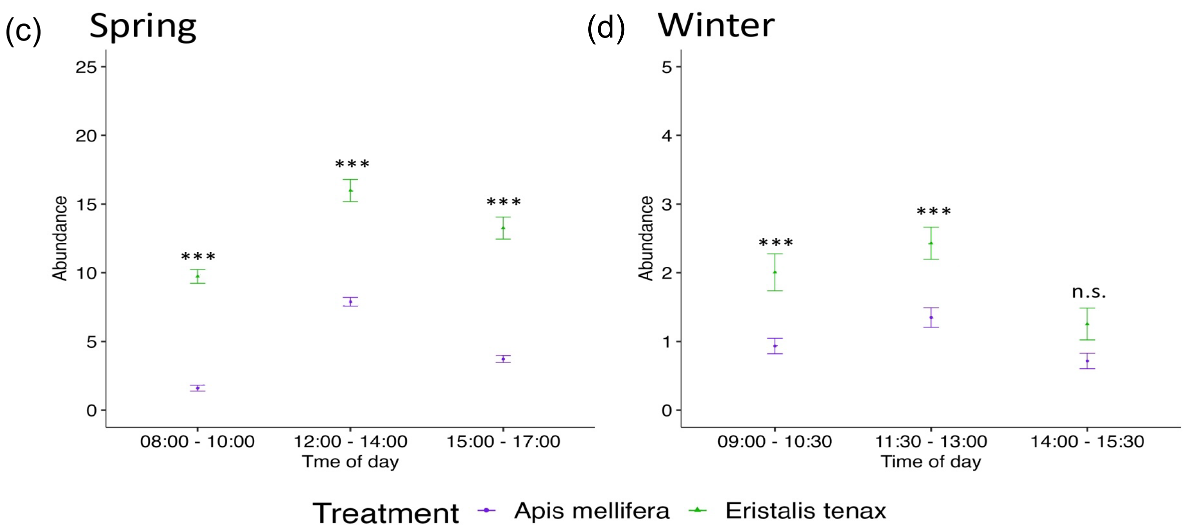

Figure 9: Abundance of European honeybees. (*Apis mellifera*) and hoverflies (*Eristalis. Tenax*) foraging on blackberry flowers based on time of day in a) Spring (September-October 2023) and b) Winter (June-August 2024). Each point on the line graph represents the mean number of visitors per seven-meter transect (± SE), with sample sizes ranging from 30 to 120 transects in spring and 30–90 transects in winter. Different colours distinguish species for clarity. Significant differences between activity of *E. tenax* and *A. mellifera* at the different times of day are denoted by asterisks ($p < 0.05$*, $p < 0.01$**, $p < 0.001$***); n.s. = non-significant).

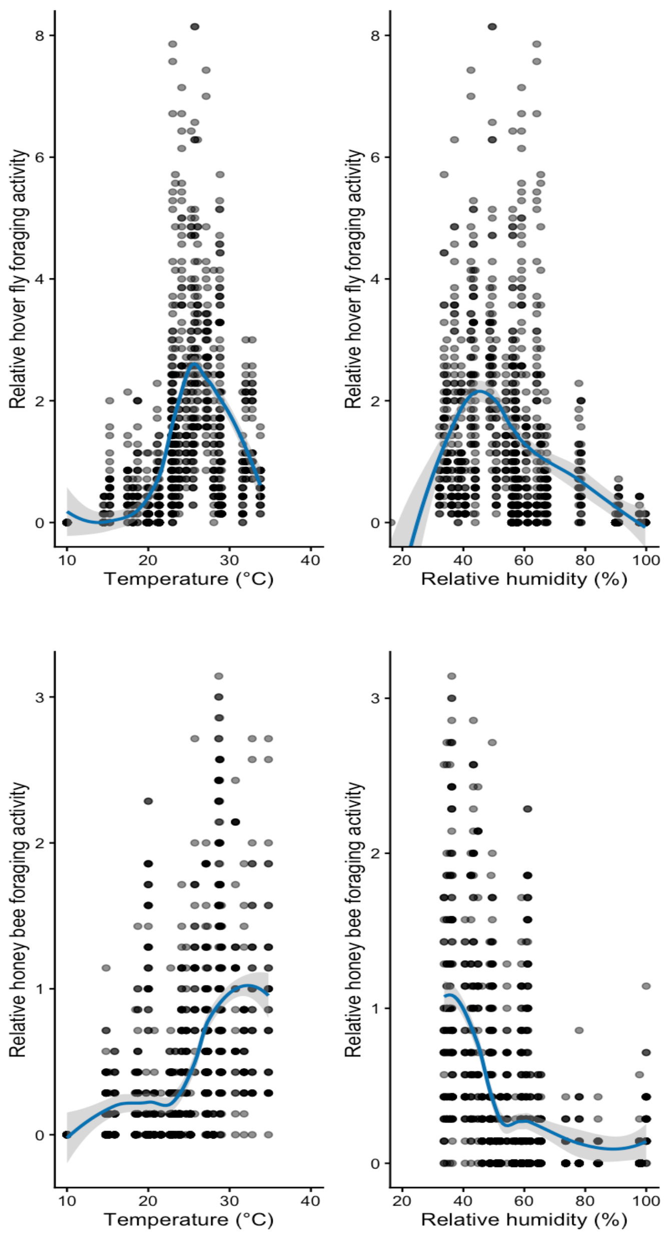

Figure 10: Relative foraging activity of the hoverfly, *Eristalis tenax* (top) and the honeybee, *Apis mellifera* (bottom) under different temperature (left) and relative humidity (right) conditions in blackberry tunnel surveys at Site 1. Data for *E. tenax* have been standardised to account for variations in stocking rate during and between trials (individual data points represent the average count of foraging *E. tenax* in transects expressed as a percentage of the number of stocked flies at each survey date). As a fixed stocking rate was used for honeybees, honeybee foraging activity data points represent the average number of foraging honeybees per 7m survey transect. Solid blue lines represent LOESS-smoothed activity trends with shaded confidence intervals.

While both *E. tenax* and *A. mellifera* foraged throughout the full length of the tunnels, we observed that activity was slightly concentrated towards the tunnel ends (Figure 13), with this trend most pronounced for *E. tenax*. This spatial structuring was associated with proximity to the fly release points (at either end of the tunnel) and the end net barriers erected to prevent flies from leaving the tunnels (Figure 13 and Plate 7). The possibility that differences in temperature, relative humidity and light levels along the polytunnels also influenced *E. tenax* distribution was investigated in the spring trial at Site 1 (Figure 14, 15 and 16), but relatively minor variation in these environmental parameters with distance was observed. Distance along the tunnel was therefore a poor proxy for the microclimatic conditions experienced by foraging pollinators. This absence of climatic gradient may have been in part due to the presence of net covers at either end of the tunnels that extended from the tunnel roofs and enclosed the headlands adjacent to the tunnel ends to prevent bird damage to the crop (Plate 7), coupled with the fact that the trials were conducted during the cooler periods of the year.

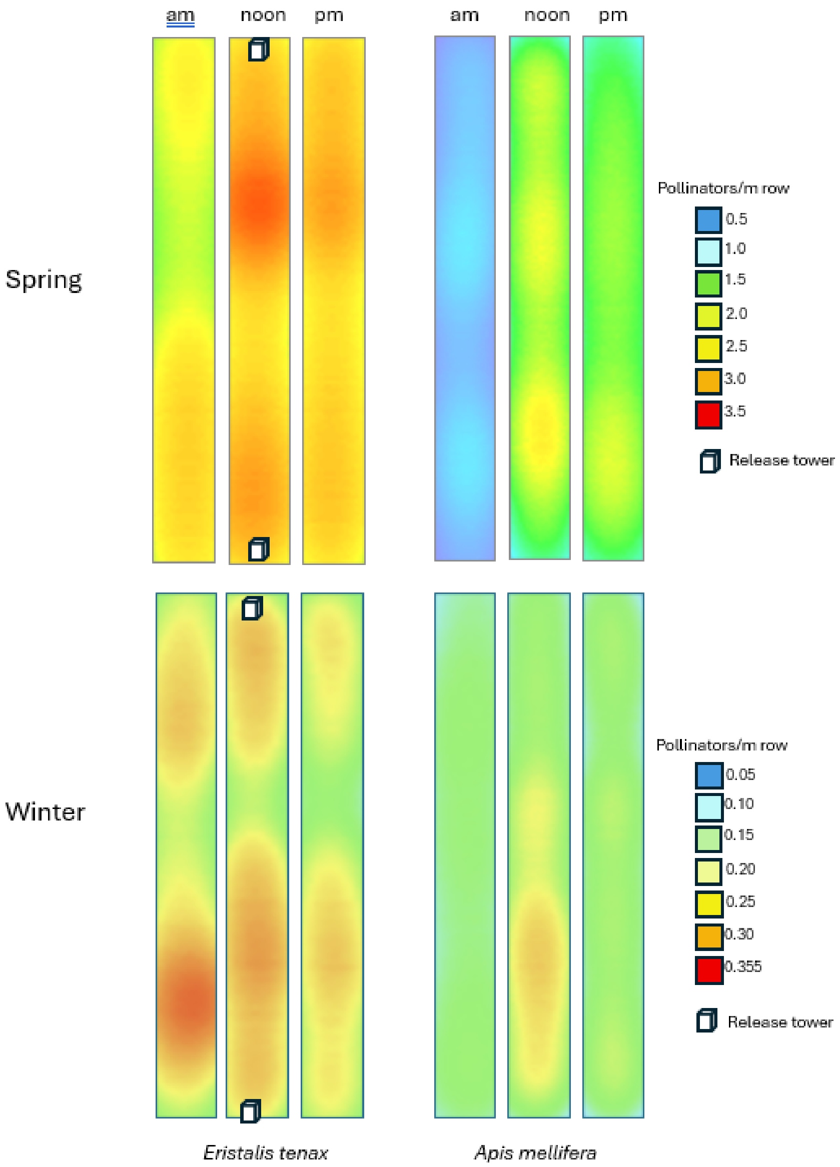

Figure 11: Average foraging activity heatmaps for *E. tenax* and *A. mellifera* in spring and winter at site 1. Surveys were conducted three times during the day (am, noon and pm). Different colours represent pollinators per meter of row. Heatmaps were generated using the geocoordinate function within Heatmapper V2.0 (Kernick et al., 2025)

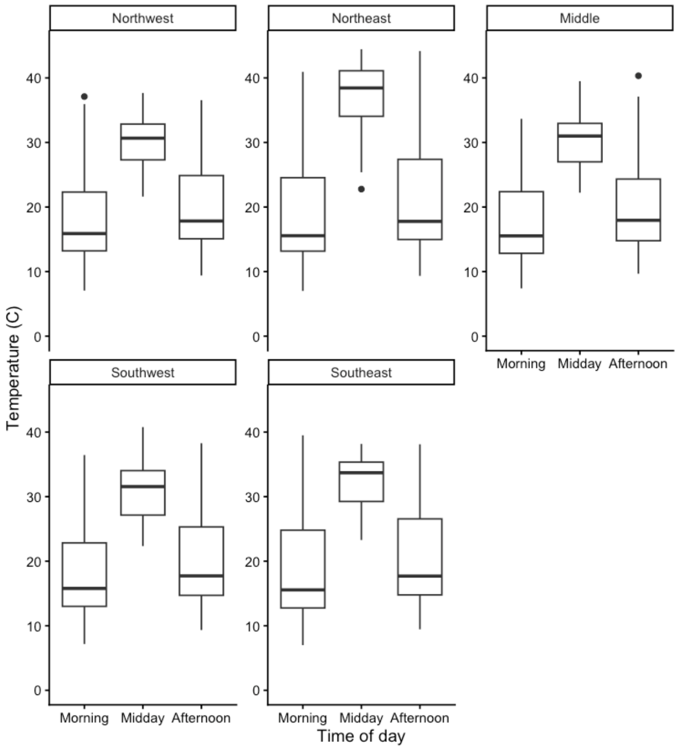

Figure 12: Temperature data recorded at 5 positions in the enclosed hoverfly tunnel at Site 1 during the spring flowering trial (September – October, 2023). Time periods were categorised as Morning (<11:00), Midday (11:00-14:00), and Afternoon (>14:00), with only observations between 06:00 and 19:00 included in analyses. Boxplots represent the interquartile range and median values, whiskers indicate data spread beyond the interquartile range, and points represent outliers.

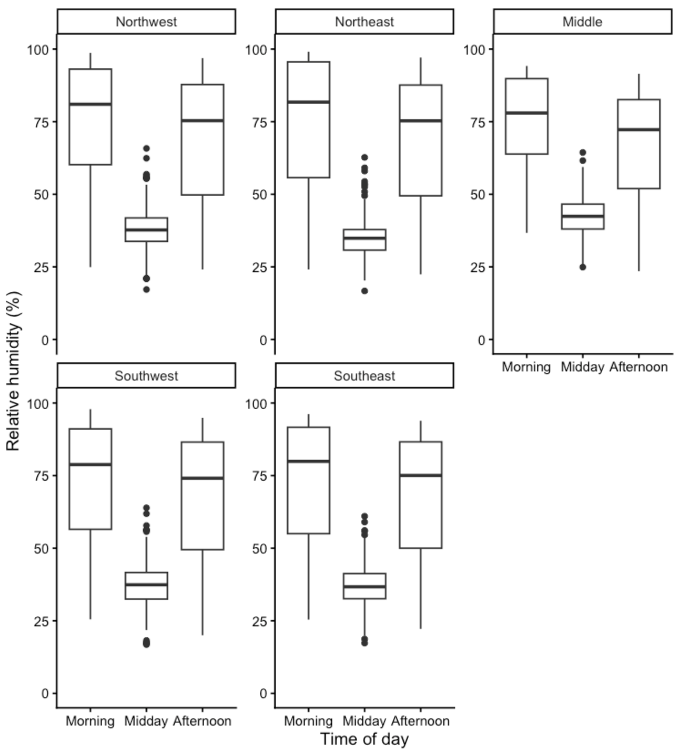

Figure 13: Relative humidity data recorded at 5 positions in the enclosed hoverfly tunnel at Site 1 during the spring flowering trial (September – October, 2023), with only observations between 06:00 and 19:00 included in analyses. Time periods were categorised as Morning (<11:00), Midday (11:00-14:00), and Afternoon (>14:00). Boxplots represent the interquartile range and median values, whiskers indicate data spread beyond the interquartile range, and points represent outliers.

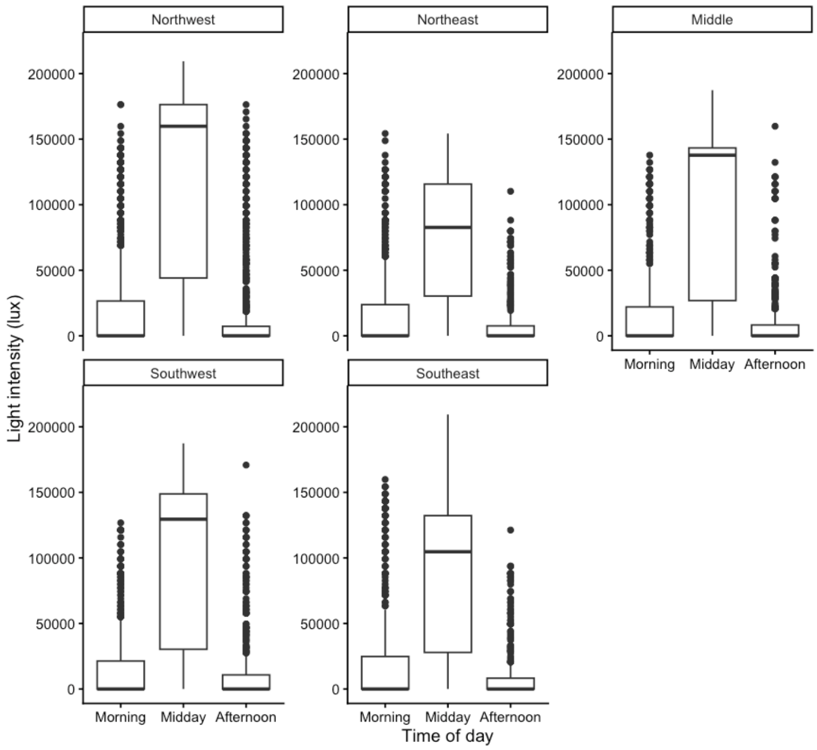

Figure 14: Light data recorded at the Northwest, Northeast, Middle, Southwest, and Southeast positions within an enclosed commercial blackberry polytunnel between, site 1, 18 September and 5 October 2023. Data are presented for the morning, midday and afternoon survey periods and represent light intensity extending across the UV, visible and near IR spectrums. Time periods were categorised as Morning (<11:00), Midday (11:00-14:00), and Afternoon (>14:00). Boxplots represent the interquartile range and median values, whiskers indicate data spread beyond the interquartile range, and points represent outliers. Values are best compared as 'relative' rather than absolute. Only observations between 06:00 and 19:00 included in analyses.

Fruit Yield and Quality

Across sites and seasons, we observed a trend towards increased fruit weight from tunnels pollinated by *E. tenax* compared with open tunnels pollinated by honeybees and other wild pollinators. There was no significant difference in weight between fruits pollinated by hand or by *E. tenax* in the spring blackberry trials at either site (ranging from 6.19 to 15.15 grams), whereas fruit pollinated in the open pollination treatments were significantly lighter compared to the hand pollination treatment at Site 2 (19% lighter) but not at Site 1 (Figure 17). There were no significant differences in the quality (% marketable fruit) of fruit produced from the *E. tenax* and open pollinated treatments in either spring trials. In all trials, self-pollinated fruit (produced from flowers physically isolated from pollinators) was of poor quality, with the majority classified as having critical defects (Table 8).

Fruit from the winter pollination trial were generally smaller and exhibited a higher proportion of defects compared to spring fruit. While this was partly due to the growing conditions during the trial, fruits from flowers pollinated by *E. tenax* were significantly ($P<0.05$) heavier on average than those produced from the open or self-pollination treatments (4.8 grams compared to 3.9 and 3.3 grams respectively), but not the hand pollinated treatment (4.2 grams) - Figure 17. Fruit from the tunnel pollinated by *E. tenax* were also of higher quality than fruit produced in the open pollination treatment (48% marketable fruit compared with 27%) – Table 7.

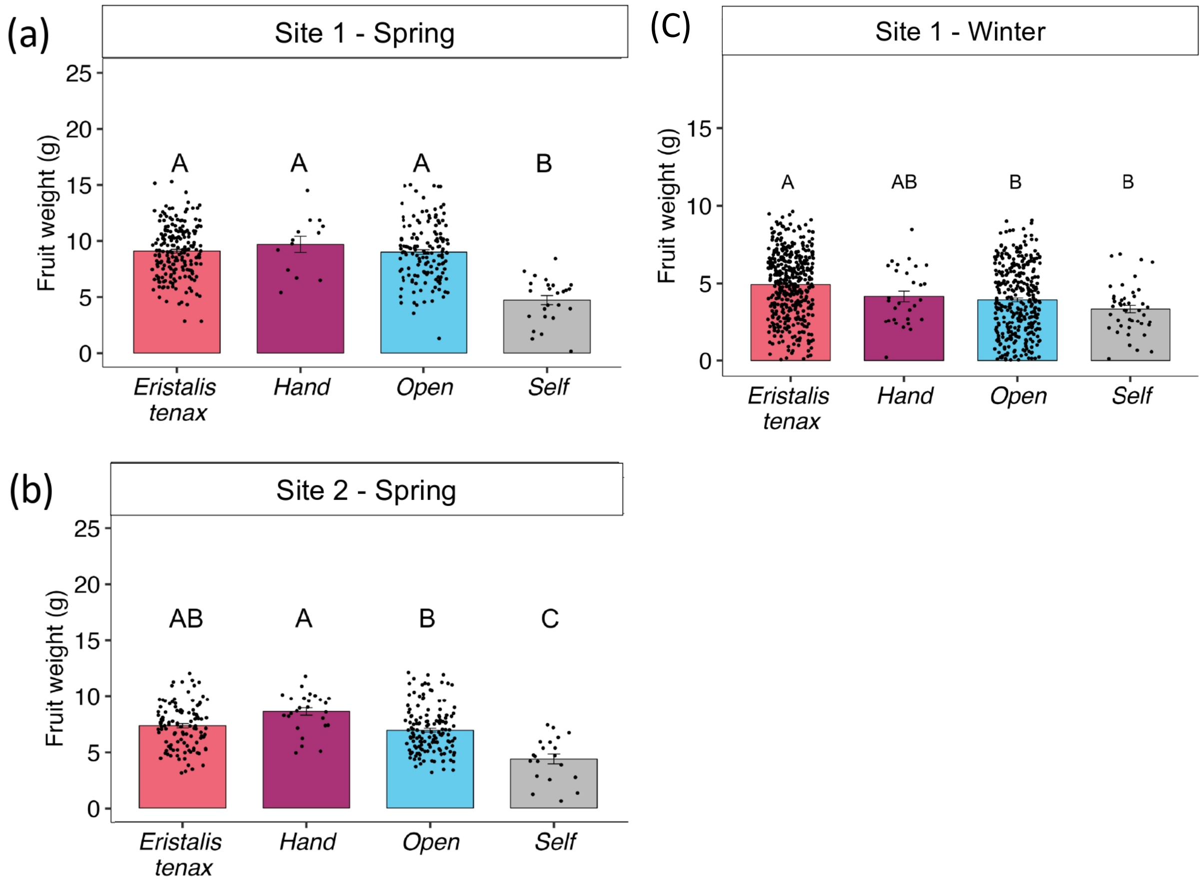

Figure 15: Fruit weight (g) ± SE (depicted as bar graphs) of blackberries harvested from *E. tenax*, hand-pollination ('Hand'), open-pollination ('Open'), and self-pollination ('Self') treatments in: a) spring (September-October 2023) at Site 1, b) spring at Site 2 and c) winter at Site 1 (June – August 2024). Fly-pollinated fruits were harvested from enclosed polytunnels, while open-pollinated fruits were harvested from open polytunnels nearby. Hand-pollinated and self-pollinated fruits were harvested from both open and enclosed polytunnels and pooled for the analysis. Individual fruit weights are jittered onto the bar graphs for clarity of replicates. Colours in bar graphs are used to distinguish between pollination treatments. Different letter combinations above bar graphs denote significant differences between pollination treatments ($p < 0.05$).

Table 7: Percentages of blackberry fruits harvested with no defects ('Marketable fruits'), stable defects, or critical defects from the *E. tenax* ('Fly' pollination), hand-pollination ('Hand'), open-pollination ('Open'), and self-pollination ('Self') treatments within polytunnel trials at Sites 1 (Spring, 2023 and Winter, 2024) and 2 (Spring, 2023) in the Mid North Coast region of New South Wales.

Site	Season	Treatment	% Marketable	% Stable Defects	% Critical Defects
1	Spring	Fly	86	4	11
		Hand	69	15	15
		Open	88	6	5
		Self	0	0	100
	Winter	Fly	48	3	49
		Hand	41	0	59
		Open	27	2	71
		Self	5	0	95
2	Spring	Fly	50	6	44
		Hand	70	4	26
		Open	55	2	43
		Self	5	0	95

Optimising Deployment Strategies for *Eristalis tenax* in Blackberries

Deployment intervals

Enclosed polytunnel and open release trials provided opportunities to observe fly survival within commercial production systems and foraging activity under different deployment strategies. We found that a deployment strategy involving multiple releases of flies at 7-10 day intervals from beginning of flowering through the main bloom period was most effective (Figure 18 a - d). This strategy allowed for a gradual build up in fly numbers as flowering progressed towards peak bloom and mitigated against any adverse effects of commercial pesticide applications through rebuilding of the adult population from freshly hatched flies (for example see Dunorlan, Tas enclosed tunnel 2022 and open release 2023 trials – Figure 19 a and c). Where less frequent releases were made, fly numbers declined after some pesticide applications (for example Mid North Coast NSW, Site 1, Spring 2023 –Figure 18 b), or from natural mortality and, in open releases, gradual migration away from the target crop into the surrounding environment (2025 Dunorlan open release, Figure 18 d).

Effect of Pesticide Applications

Fly pollinators are vulnerable to pesticide applications as they remain within the crop at night when spraying typically occurs, whereas honeybees leave the crop and return to their hives at night. Several commercial pesticides (comprising both insecticides and fungicides – see Figure 18 a-d) were applied singularly or in combination during the different trials. While some applications appeared to adversely affect fly survival, others had minimal impact. Work to generate laboratory data on the relative toxicity to *E. tenax* of a range of pesticides used in insect pollinated horticultural crops is currently underway. A summary of preliminary data for several common pesticides, including products used by the berry industry, is presented in Table 8; testing of additional products relevant to the berry industry will be undertaken in the project PH24002, "Flies as Effective pollinators for Horticulture' (2025-2030). The preliminary data highlight differences in the relative toxicity of different pesticides to *E. tenax*, even amongst products targeting similar pests. These responses suggest that, under circumstances when pesticide usage is essential, effective integration of *E. tenax* as a pollinator in berry systems may be achieved through the combination of strategies including multiple deployments of pupae through flowering, careful selection of crop protection products to minimize impacts on *E. tenax* (where more than one permitted product option exists) and use of critical control thresholds in preference to preventative or calendar-based pesticide applications.

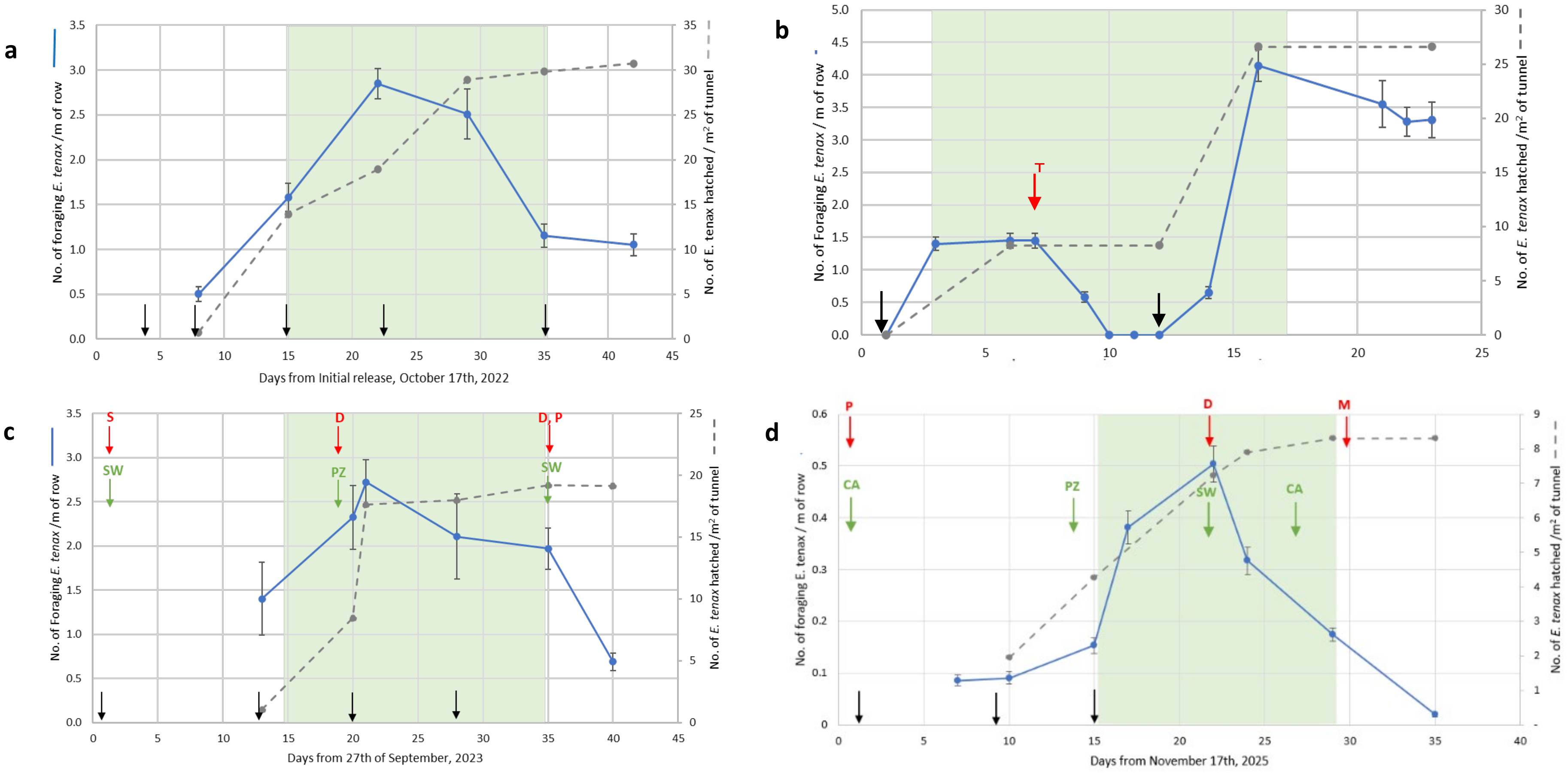

Figure 16: Fly population dynamics (Number of foraging flies/m of row in spot counts (●) and the accumulated number of flies hatched from pupal releases (●) over time in blackberry pollination trials in enclosed tunnels at Site 1 on the Mid-North Coast (NSW) in spring, 2023 (a) and winter, 2024(b) and open release trials in Dunorlan, Tasmania in 2023 (c) and 2025 (d). The main period of blackberry bloom in each trial is indicated by the green shaded section. Number and timing of fly deployment events in each trial are indicated by the black arrows ( ) above the x-axis. Number, timing and type of insecticide ( ) and fungicide ( ) applications are indicated by arrows and the corresponding notations: T = Transfrom (a.i. Sulfoxaflor), S = Success (a.i. Spinetoram), D = Dipel (a.i. *Bucillus thuringiensis*), P = Pirimor (a.i. pirimicarb), M = Mainman (a.i. flonicamid), SW = Switch (a.i. Cyprodinil and Fludioxonil), PZ = Penncozeb (a.i. Mancozeb) and CA = Captan (a.i. N-trihalomethylthiop derivative).

Table 8: Toxicity of some commonly used pesticides to *Eristalis tenax* in laboratory oral and contact assays. Toxicity ratings are based on mortality rates 72 hours after exposure: Very Low = <10%, Low = 10 – 25%, Moderate = 25 – 50%, High = 50 – 90% and Very High = >90%. Assay results were standardized against mortality rates for untreated (control) flies drawn from the same population and held in the same conditions over the same time period as the treated flies. Products used in berry crops are denoted by the superscripts after the product name: [1] = Used in Rubus crops; [2] = Used in blueberry crops (Note that some active ingredients are marketed under multiple product names (brands); the product name shown indicates the brand tested; [3]Amistar Top is not registered for use on berry crops in Australia, but the related product Amistar 250, containing Azoxystrobin as the sole active ingredient is currently permitted for use on Rubus and blueberry crops.

Product	Category	Active Ingredient(s)	Target Pests	Reference Product Rate / A.I. Concentration at 200L/ha Water Rate	Concentrations Tested	Toxicity Rating		
						Oral	Direct Contact	Indirect Contact
Amistar Top[3]	Fungicide	200g/L azoxystrobin + 125g/L difenaconazole	Leaf blights, sclerotinea and mildews	1L/ha / 1000ppm + 625ppm	1000ppm + 625ppm	Moderate	Moderate	Very Low
					250ppm + 156ppm	Low	Moderate	Very Low
					63ppm + 39ppm	Low	Low	Very low
Dominex Duo	Insecticide	100g/L Alpha-Cypermethrin	Broad Spectrum Insecticide	300ml/ha / 150ppm	150ppm	Very High	Very High	Very High
					38ppm	Very High	Very High	Very High
					9ppm	Very High	Very High	Very High
Mavrik Aquaflow	Insecticide	240g/L Tau-Fluvalinate	Broad Spectrum Insecticide	300ml/ha / 360ppm	360ppm	Very High	Very High	Very High
					90ppm	Very High	Very High	Low
					23ppm	Moderate	Very High	Very Low
Dipel [1,2]	Insecticide	*Bacillus thuringiensis*	Lepidopteran caterpillars	100g/ha / 500ppm	500ppm	Low	Very low	Very low
Pirimor[1,2]	Insecticide	500g/Kg Pirimicarb	Aphids	500g/ha / 1250ppm	1250ppm	Very High	Very High	Very High
					313ppm	Very High	Very High	Moderate
					78ppm	Very High	Very High	Low
Movento[2]	Insecticide	240g/L Spirotetramat	Green peach aphid Grey cabbage aphid Silverleaf whitefly Diamondback moth	200ml/ha /	240ppm	Very Low	Very Low	Very Low
					60ppm	Very Low	Very Low	Very Low
					15ppm	Very Low	Very Low	Very Low

Stocking rates

Stocking rate effects on fruit yield were assessed using a pooled fruit weight dataset drawn from the four enclosed tunnel trials (Dunorlan, Tas -2022; Mid-North Coast, NSW Site 1, 2023 and 2024 and Site 2, 2023). Bee and fly pollinated fruit weight data were standardised against hand pollinated fruit weight data to account for environmental variability between trials and tunnel level treatments. The pooled dataset shows optimal fruits weights were achieved when fly foraging activity was 1.5 – 3 flies per meter of row (corresponding to one side of a row of plants). When fly foraging activity exceeded this level, fruit weight declined, indicating that it may be possible to adversely impact pollination outcomes through overstocking. Similar overstocking responses have been observed for *E. tenax* in sweet cherries (Spurr and Rowbottom, 2025) and for bumblebees in raspberry crops in Argentina (Saez et al. 2014). Across the trials, honeybee foraging activity up to 2.2 bees/m of row was observed and, up to this point, fruit weight responses to different levels of foraging activity were similar for both bees and flies. While mixed foraging activity of 1.5-3 insects (bees and flies) per meter of row may be optimal, further data would be required to establish whether there is a negative response to higher rates of honeybee foraging activity.

Fly Dispersal and Retention in Open Releases

The 2025 trial at Dunorlan represented the first documented, significant (in terms of scale) open release of *E. tenax* into a commercial berry production system in Australia. The primary objectives of the trial were to collect fly dispersal and retention data from an open system to inform deployment strategies for future large scale experimental releases. The key results are presented in Figure 20 (a to c). From 2 weeks prior to peak bloom, a total of 150,000 *E. tenax* pupae were deployed in 3 weekly drops at the mid-point of 13 tunnels, comprising two central blocks (606 and 608) within the 1.7ha study area (Figure 20 c). A final hatching rate of 94% was achieved across all releases. Peak fly foraging activity was observed in the trial on the 9th of December survey, mid-way through the main bloom period (Figure 20 b). At the time of this survey, 12% of all flies that had hatched to that point were visually foraging on blackberry flowers (in contact with the flower) within the study area. A further 15% of flies were actively flying around or resting on blackberry plants and there were likely many others resting within the leafy canopy that were not observed in the survey. Spatial data for fly foraging activity indicate progressive movement of flies into the adjacent tunnel blocks from the central release point over distances of up to 130m (Figure 18 a). On the 9th of December, average foraging activities of 0.76 and 0.87 flies per meter of row were observed in blocks 605/607 and 609 respectively located either side of the release point (blocks 606/608), where average foraging activity was 1.53 flies/m of row (Figure 20 c). Average foraging activity within the study area on the 9th of December and for the 4 surveys conducted during the main bloom period (4th to 16th of December) was 1.09 and 0.65 *E. tenax*/m row and 0.64 and 0.58 bees/m of row respectively. In the later stage of flowering, *Eristalis tenax* activity declined, this may have been avoided by a fourth deployment of pupae, or by moving the three deployments of pupae one week later relative to flowering. Overall, the results demonstrate that a strategy involving staggered deployment of 90,000 flies/ha from appropriately spaced release points can result in *E. tenax* contributing significantly to crop pollination in commercial blackberry tunnels.

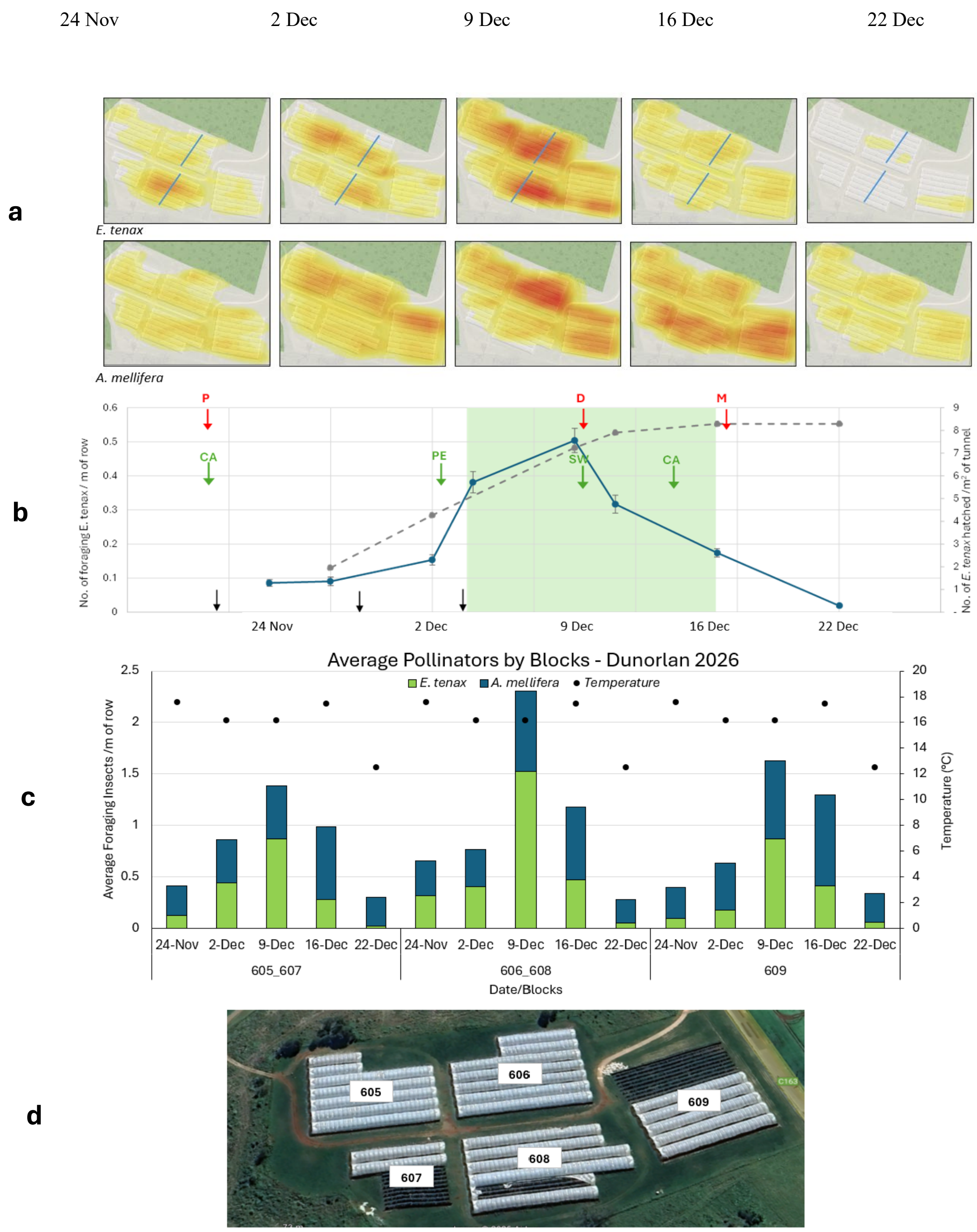

Figure 17: Dunorlan, Tas 2025 open release trial. a) Foraging activity heat maps for *E. tenax* and *A. mellifera* during flowering within the study area. Flies were deployed as pupae at the mid-point of each tunnel in the central blocks (606 and 608 – along the blue lines superimposed on the heat maps) and spread from there to the adjacent tunnel blocks (605, 607 and 609) over time b) Fly population dynamics (average number of foraging flies/m of row across the entire study area in spot counts (●) and the accumulated number of flies hatched from pupal releases (●) over time. The main period of blackberry bloom within the trial is indicated by the green shaded section. Number and timing of fly deployment events in each trial are indicated by the black arrows ( ) above the x-axis. Number, timing and type of insecticide ( ) and fungicide ( ) applications are indicated by arrows and the corresponding notations: D = Dipel (a.i. *Bucillus thuringiensis*), P = Pirimor (a.i. pirimicarb), M = Mainman (a.i. flonicamid), SW = Switch (a.i. Cyprodinil and Fludioxonil), PE = Penncozeb (a.i. Mancozeb) and CA = Captan (a.i. N-trihalomethylthiop derivative).c) Average numbers of foraging *A. mellifera* (■) and *E. tenax* (■) in spot counts conducted across the 3 tunnel blocks of the study area. The data for both pollinators have been stacked to show their relative abundance. Mean air temperature data during each survey are shown above the stacked columns (●).

Habitat Modifications

Across the observation period, 40 invertebrate taxa across nine orders were recorded within the artificial ponds (Table 10). These included a diverse range of aquatic, semi-aquatic, and terrestrial groups such as beetles, flies, true bugs, spiders, ants, bees, dragonflies, damselflies, springtails, and slugs. Many of the taxa observed are associated with important on-farm ecological functions, including pollination, nutrient cycling, and predation, indicating that the ponds supported a functionally diverse invertebrate community within the cropping system.

Eristalinae flies were among the earliest and most consistent taxa observed in plant-substrate ponds. Eggs were first detected nine days after deployment, followed by larvae and later pupae in the surrounding soil. Fly eggs and larvae were found exclusively in plant-substrate ponds, with no evidence of breeding in water-only ponds. Three species were identified: the European drone fly (*E. tenax*; Figure 21 a), the green hoverfly (*Austalis copiosa*; Figure 21 b), and the golden native drone fly (*E. punctulatus*; Figure 21 c). These observations demonstrate that plant-substrate ponds can help to support the full life cycle of key pollinating fly species under commercial farm conditions.

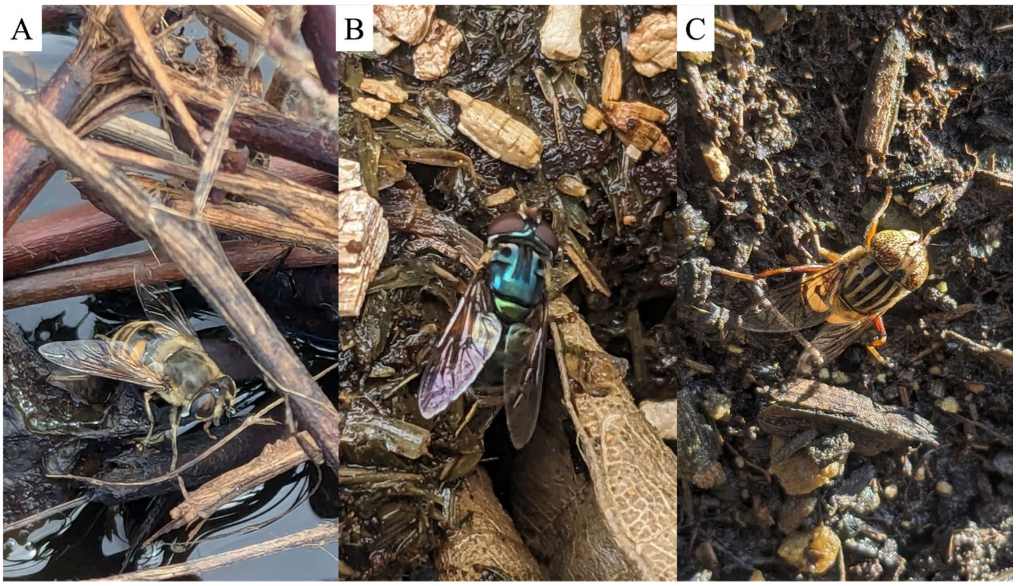

Figure 18: Eristaline syrphid fly species that were reared from the plant-substrate ponds: (A) the European drone fly *Eristalis tenax*, (B) the green hoverfly *Austalis copiosa*, and (C) the golden native drone fly *Eristalinus punctulatus*.

In addition to breeding activity, the habitat ponds supported a range of other invertebrates interactions. Honeybees (*A. mellifera*) were regularly seen drinking water from both pond types. Predatory taxa such as spiders, lady beetles, and dragonflies were also observed, alongside detritivores such as springtails. Several taxa commonly associated with pest activity, including mosquitoes, leafhoppers, and slugs, were also recorded. Together, these observations indicate that artificial ponds function as multi-purpose habitat features within the farm, supporting a range of beneficial and non-beneficial invertebrates.

While artificial ponds supported a diverse invertebrate community, including pollinators and other functionally important taxa, the extent to which these communities contribute to ecosystem services within adjacent crop fields remains unclear. Future research is required to establish whether invertebrates developing within ponds move into crop areas and provide measurable benefits such as pollination or pest suppression. Additionally, although several taxa associated with pest activity were recorded, it is not yet known whether these species are specifically attracted to the ponds or are simply utilizing them opportunistically without increasing their overall abundance within the farm. Understanding these dynamics will be important for assessing potential trade-offs and informing the practical deployment of pond-based habitats in commercial farming systems.

Table 9: First recorded occurrence of invertebrate taxa utilising artificial ponds deployed within a commercial berry farm on the Mid North Coast of New South Wales, Australia. 'Days' indicates the number of days after pond deployment when each taxon was first observed. 'Plant' ponds contained decaying blackberry leaves and stems with water, while 'Water' ponds served as controls and contained water only; 'Both' indicates taxa recorded in both treatments. 'Order' and 'Family' refer to taxonomic classification, and 'Species' indicates the number of species identified within each family.

DAYS	POND TREATMENT	ORDER	FAMILY	# SPECIES
9	Plant	Diptera	Syrphidae	3
13	Plant	Diptera	Sepsidae	2
13	Plant	Coleoptera	Staphylinidae	4
13	Both	Diptera	Culicidae	1
13	Water	Hemiptera	Nepidae	1
13	Water	Coleoptera	Hydrophilidae	3
18	Plant	Coleoptera	Scarabaeidae	3
18	Plant	Coleoptera	Coccinellidae	1
20	Plant	Araneae	Lycosidae	1
20	Both	Coleoptera	Dytiscidae	1
23	Both	Hymenoptera	Apidae	1
23	Plant	Hymenoptera	Formicidae	1
27	Both	Diptera	Ephydridae	1
27	Both	Diptera	Empididae	1
29	Plant	Diptera	Platystomatidae	1
29	Water	Odonata	Coenagrionidae	1
29	Water	Odonata	Libellulidae	1
29	Plant	Diptera	Muscidae	1
31	Both	Blattodea	Rhinotermitidae	1
31	Both	Poduromorpha	Hypogastruridae	1
31	Plant	Araneae	Araneidae	1
31	Plant	Araneae	Tetragnathidae	1
31	Plant	Araneae	Theridiidae	1
31	Plant	Coleoptera	Mycetophagidae	1
31	Plant	Coleoptera	Ptiliidae	1
31	Plant	Hemiptera	Cydnidae	1
31	Water	Coleoptera	Chrysomelidae	1
31	Water	Hemiptera	Cicadellidae	1
31	Water	Stylommatophora	Limacidae	1
34	Plant	Diptera	Calliphoridae	1

Raspberries

Following earlier successful small cages trials (Davis, A. et al 2026), a single trial evaluating *E. tenax* as a raspberry pollinator in an enclosed tunnel level trial conducted during spring, 2024 at a site on the Mid-North Coast of NSW. The trial was prematurely terminated after 2 weeks because of development of issues with declining plant health and mold growth on fruit within the enclosed tunnel *E. tenax* treatment. These problems were likely caused by a combination of factors including increased humidity levels and incomplete utilisation of nectar within the *E. tenax* treatment, leading to mold development on the forming fruit. Despite the short time over which the trial ran, some foraging and fruit data was collected.

Average foraging activity of *E. tenax* within the trial over the 10 surveys that were completed was 0.61 flies/m of row, compared with 0.77 honeybees/m of row in an adjacent open pollinated tunnel. Despite comparable stocking rates in this trial and the winter blackberry trial (17 pupae/m2 in this trial vs 12 to 33 pupae/m2 in the blackberry trials), average foraging activity in the blackberry trial was 2 times greater. This may be linked to the visibly larger quantities of nectar produced in the raspberry trials, resulting in individual flies foraging fewer flowers and for shorter periods of time. As in the blackberry trials, *E. tenax* foraged most actively at lower temperatures (22°C and below).

Yield and Quality

Fruit harvested from the raspberry trial was restricted to one day of flower tagging (27th August). From this treatment date there was a range of fruit sizes with the heaviest fruit being 9.86, 9.28 and 8.96g for open (*A. mellifera*), *E. tenax* and hand pollinated treatments respectively. Despite the similarity of heaviest fruit between treatments, during this treatment date there was a significant difference in the fruit weight between fly, open or hand pollinated treatments (*p-value*= 0.008) with bees producing significantly heavier average fruit weights (Figure 22). The difference in the quantity of harvested fruit between the open and fly treatments is a result of fruit ripening faster in the enclosed fly tunnel.

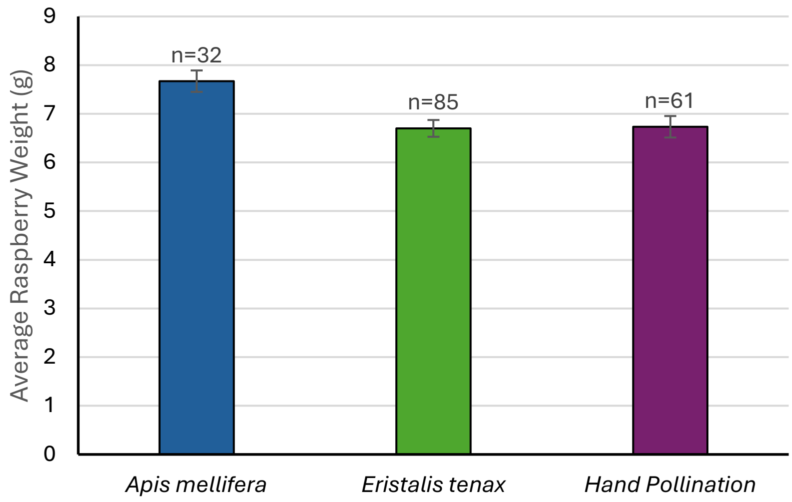

Figure 19: Average raspberry weight (g) between *A. mellifera* (open), *E. tenax* and hand pollination treatments. Number of fruit used in the measurement represented by n above bars. Error bars are standard errors.

Blueberry Trials

Blueberries (Vaccinium spp.) are a crop-species complex and pollinator dependency can vary differ considerably across different cultivars and hybrids. Most growers plant multiple different cultivars due to differences in flowering phenology and frost requirements and to meet market needs. In NSW, we focused trials on southern highbush (V. corymbosum).

We conducted an initial investigation of the effectiveness of two Eristalinae flies, the common drone fly (*E. tenax*) and the golden drone fly (*E. punctulatus*) as blueberry pollinators in a cage-based trial conducted at a blueberry orchard on the New South Wales mid-north coast. The inclusion of E. punctulatus was informed by findings from PH16002, which identified this species as an effective pollinator, and given its smaller body size relative to *E. tenax*, it was hypothesized that it may be better suited to pollinating small, tubular blueberry flowers. We also investigated how the provision of additional floral resources (floral strips) influenced pollinator activity.

Methods

Pollination Efficiency of Flies

Pollination efficiency assessments of *E.* tenax and *E. punctulats* were conducted in small cage trials at a Costa Farms blueberry orchard on the mid-north coast of New South Wales (30.3° S, 153.1° E). Trials were conducted in a netted block of the blueberry cultivar Snowchaser (patented US20080196128) during the autumn/winter flowering period (April–June 2024). The Snowchaser cultivar is partially self-fertile, but demonstrates improved fruit set and quality with insect-mediated pollination. Four mesh cages were installed over groups of four blueberry bushes (16 plants total), with two cages assigned to *E. tenax* and two cages assigned to *E. punctulatus* (Plate 10). The cages were designed to retain the stocked flies and exclude other pollinators, whilst allowing the flies to freely forage on the enclosed plants. An additional 4 non-caged plots of 4 plants each were set up adjacent to the cages as an 'open' pollination treatment. The predominant pollinators in these plots were stocked European honeybees (*Apis* mellifera). *E. tenax* and *E. punctulatus* were deployed into the cages over 4 equal weekly stockings, delivering approximately 500 adult flies in total to each cage.

Floral visitation surveys were conducted to quantify pollinator activity under field conditions in both the caged and open plots. Visitation rates of *E. tenax*, *E. punctulatus*, and *A. mellifera* to blueberry flowers were recorded using a standardized transect method. Each transect score consisted of an observer walking slowly (30 seconds per plant) around each plot scoring foraging activity on flowers. Fly surveys were conducted outside cages to avoid disruption to the flies and conducted between 08:00 and 14:00 to capture peak daily pollinator activity. One to 3 surveys were performed per week and conducted in all weather conditions apart from rain.

As outlined for the Rubus trials, three pollination treatments were applied weekly to 10 tagged flowers per plant (40 per treatment per cage): (i) hand-, (ii) self-, and (iii) open-pollination. Tagged blueberry fruits were harvested at maturity and weighed.

Plate 10: (Left to Right) Image of the trial set up showing a single bee plot marked with pink flagging tape and two individual netted cages for *E. tenax* and *E. punctulatus, E. tenax* foraging on a blueberry flower and *E. punctulatus* foraging on blueberry.

Habitat Modification with Floral Strips

Trials to test the effectiveness of additional floral resources (forage strips) to support blueberry pollinator communities under commercial production conditions were conducted in 5 blueberry blocks at Costa farms. Three blocks were planted with the cultivar 'Snowchaser', while the remaining blocks were intercropped with other cultivars. All blocks were enclosed with bird netting and comprised 37–45 rows of blueberry plants, with rows spaced approximately 2 m apart and separated by grass-dominated interrow strips containing predominantly non-flowering plant species. Flowering seed mixes (two in total) were established within selected interrow areas in April 2024, alongside existing grass inter-rows which served as controls. Implementation of forage strips was undertaken in collaboration with farm agronomists to ensure compatibility with standard farm management practices. Planting was conducted approximately two months prior to crop flowering to ensure overlap between forage strip bloom and blueberry flowering.

Once forage strips had established, insect floral-visitor surveys were conducted across a three-month survey period coinciding with blueberry early flowering (June), peak flowering (July), and late flowering/peak fruiting (September). For each survey, a 30 m walking transect was conducted to assess the abundance and diversity of insect flower visitors along the crop row and nearby interrow, separately, for each of the three treatments (mix 1, mix 2, and grass interrow strips) per block. Therefore, 30 surveys per treatment were conducted per survey period (90 in total). Blueberry cultivars were surveyed separately to determine if insect flower visitor communities differed between blueberry cultivars in the same farm. Voucher specimens of floral visitors were collected in the field and later identified to the lowest possible taxonomic grouping with relevant keys.

Additional surveys of honeybees were conducted on blueberry and nearby inter-row flowers to determine the movement of honeybees within crop fields. The method involved observers following individual honeybees as they foraged on blueberry and/or forage strip flowers. Each survey began in a blueberry row within one of the five blocks where forage strips were planted. The observer noted the starting flower, the total number of flowers visited, and plant species the honeybee visited within the 3-minute time-period.

Results and Discussion

Pollinator Foraging Activity

A total of 324 surveys were conducted over four weeks (May–June 2024), spanning environmental conditions ranging from 20–30°C and 31.4–88.7% relative humidity. *Eristalis tenax* was the most abundant floral visitor recorded, while *A. mellifera* was the least abundant (Figure 23). This was notable given that surveys were conducted within 10 to 60m of an active honeybee hive, indicating limited honeybee visitation to crop flowers under these conditions. Further, *E. tenax* showed consistently higher visitation rates across all time periods, with peak activity for this species occurring in the early morning (08:00, 12 flies visiting flowers per cage). Similarly, activity of *E. punctulatus* was highest in the morning at 10am (4 flower visitors per cage) and appeared to progressively decline thereafter. In contrast, average activity of A. mellifera was lowest early in the day and built through the morning into the afternoon.

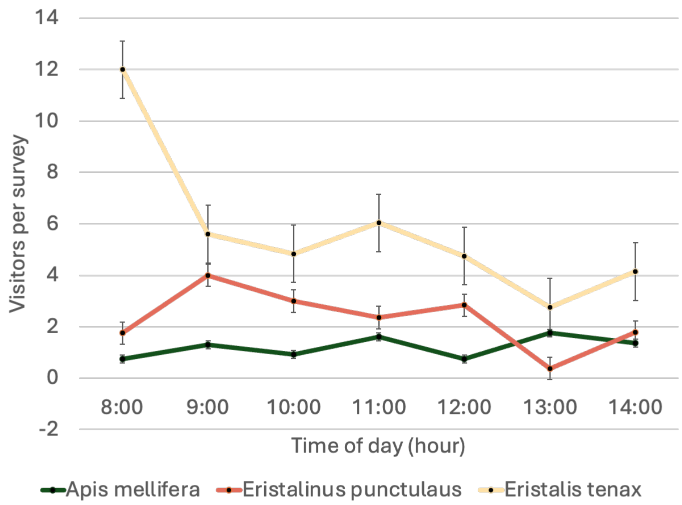

Figure 20: Average number of flower-visitors per survey of four blueberry plants across the day (08:00 – 14:00) in a commercial blueberry farm in the Mid North Coast of New South Wales, Australia. Flower-visitors included honeybees (‘*A. mellifera’)* and hoverflies (‘*E. punctulatus’* and ‘*E. tenax*’). Hoverflies were contained within in-field cages while honeybees were free-flying. Different colors indicate different flower-visitors. Error bars represent SE.

Pollination Efficiency of Eristalinae Flies

Following four weeks of pollination treatments and flower tagging, 1,513 blueberry fruits were harvested and individually weighed. Fruit weight varied across sampling weeks; however, consistent treatment-level patterns were observed. Open-pollinated fruits were generally the largest, while self-pollinated fruits were consistently the smallest across all weeks

(Figure 24). Both fly species enhanced pollination of blueberry compared to self-pollination. The hoverfly *E. tenax* typically produced slightly larger fruits than *E. punctulatus*, although this pattern varied between weeks (Figure 24). This temporal variation was likely associated with environmental conditions, with cooler and wetter conditions experienced during Weeks 1 and 3 (5–6 rain days per week were recorded in these weeks).

Overall fruit weights were lower than expected from all treatments for this cultivar. This was attributed to a rust infection affecting the trial block at the time the experiment was conducted. As the infection occurred across all treatments, relative differences among pollination treatments remain comparable.

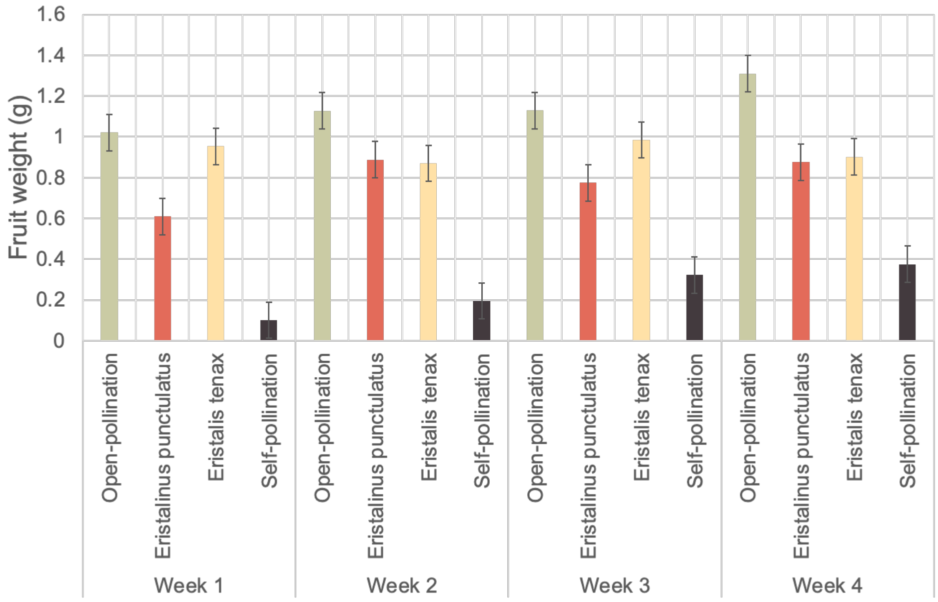

Figure 21: Weekly (Week 1 – 4) variation in blueberry fruit weight (g) across pollination treatments. Pollination treatments included open-pollination (primarily honeybees), fly-pollination (‘*E. tenax*’ and ‘*E. punctulatus*’) within in-field cages, and self-pollination (no insect visitors to flowers).

Pollinator Surveys (with and without floral strips)

Pollinator attractiveness to flowers within forage strip mixes varied. The most attractive flower to pollinators (in terms of total pollinator abundance) across all sampling periods was sweet alyssum in forage strip mix 1. Aside from sweet alyssum, buckwheat, bee-ready brassica, and clover, eight other flowering plant species were visited by pollinators in varying numbers across sampling periods. This data formed part of two different PhD student projects and is confidential until student completion.

Outputs

Table 10: Output summary

Output	Description	Detail
Industry article/magazine	Rader R, Jones J, Santos KCBS, Schmidt LA, Preradovic J, Dawson B, Perović DJ, Davis A, Rocchetti M, Scalzo J, Shermeister B, Broussard M, Cutting B, Evans L Better pollination knowledge can grow better berries	Australian Berry Journal Winter 2023, Edition 15; 44-46 https://issuu.com/berriesaustralia/docs/abj-winter-2023-edition-15/s/25646759
Conference	Raylea Rowbottom Efficacy of flies as Berry Pollinators and Current Pollination Research	Tasmanian Fruit Growers Conference June 15-16, 2023
Conference	Romina Rader Future-proofing Berry Pollination Services	XIII International Rubus and Ribes Symposium, Portland Oregon, USA July 16-21, 2023
Conference	Abby Davis Dipteran pollination in Australian commercial cropping systems	International Congress of Dipterology, Reno, Nevada, US July 2023
Industry meeting	Cameron Spurr, Romina Rader, Raylea Rowbottom Hoverflies as Effective Berry Pollinators	Berry Growers Meeting, Coffs Harbour November 19, 2023 Delivered to berry growers and industry stakeholders, highlighting results from recent pollination trials and efficacy comparisons in NSW
Conference	Jelena Preradovic The outcome of interactions among flower visitors on Australian berry farms	7th European Congress of Conservation Biology June 19, 2024
TV Program	Cameron Spurr, Raylea Rowbottom, Romina Rader, Abby Davis, Lena Schmidt, Jelena Preradovic Interview at Costa NSW and another privately owned farm to showcase the research conducted in the area, May 22-23 2024	ABC Landline Interview, NSW July 7, 2024 (broadcast) https://www.abc.net.au/news/rural/programs/landline/2024-07-07/flower-flies:-using-flies-as-pollinators/104068838
News Article	Cameron Spurr, Raylea Rowbottom, Romina Rader, Abby Davis, Lena Schmidt, Jelena Preradovic Flower fly pollination could alleviate Australia's reliance on honeybees for crops as varroa mite impact plays out	Landline article and video Released July 6 and 7, 2024 https://www.abc.net.au/news/2024-07-07/flower-fly-pollination-honeybees-trial-berries-crops/104054082
Conference	Abby Davis Supporting fly pollinators in crop agroecosystems	International Congress of Entomology, Kyoto, Japan August 26, 2024

Industry meeting	Jessie Moyses How do floral interrow plantings influence the abundance and diversity of pollinators, pests and natural enemies, and pollination in blueberry orchards?	Costa Meeting, Coffs Harbour Delivered to Costa, highlighting results from recent trials January 13, 2025
Conference	Raylea Rowbottom and Abby Davis Independent presentations across research on flies as pollinators	BerryQuest International February 27, 2025 https://berries.net.au/resource/video-dr-abby-davis-university-of-new-england/ https://www.youtube.com/watch?v=YQhw4lybjx8
Industry article/magazine	Schmidt LA, Jelinek S Addressing pollination challenges in cucurbit production: enhancing resilience in Australia's horticultural sector	Australian Grower Winter 2025; 119 https://ausveg.com.au/knowledge-hub/addressing-pollination-challenges-in-cucurbit-production-enhancing-resilience-in-australias-horticultural-sector/?utm_source=facebook&utm_medium=social&utm_campaign=ausveg&utm_content=ausveg#sq_i2j87fpzdw
Conference	Lena Schmidt Diversifying pollination: a path to strengthening cucurbit production in Australia	Hort Connections June 5, 2025
Conference	Jessie Moyses How interrow floral strips can benefit pollinators and blueberry production	International Congress for Conservation Biology Symposium Convenor and Organiser June 17, 2025
Conference	Jelena Preradovic Habitat interventions to support wild insect pollinators in protected agricultural production systems	International Congress for Conservation Biology June 17, 2025
Industry article/magazine	Schmidt LA, Preradovic J, Davis A, Moyses J, Tulloch A, Spurr C, Rowbottom R, Courtois MF, Hocking B, Shermeister B, Rader R Supporting pollinators: looking beyond flowers and bees for enhanced berry production	Australian Berry Journal Winter 2025, Edition 23; 78-81 https://berries.net.au/resource/supporting-pollinators-looking-beyond-flowers-and-bees-for-enhanced-berry-production/
Radio interview	Abby Davis Live radio interview on flies as pollinators in Australia	ABC New England Northwest Breakfast with Kristy Reading. 20 April 2026 at 09:10.
News article	Abby Davis Flies found to be effective pollinators of berry crops	Phys.org published on 14 April 2016 https://phys.org/news/2026-04-flies-effective-pollinators-berry-crops.html

TV interview	Abby Davis Study finds flies to be as effective at pollinating berries as honeybees	NBN News North West on 20 April 2026 https://www.nbnnews.com.au/2026/04/20/study-finds-flies-to-be-as-effective-at-pollinating-berries-as-honeybees/
Scientific publication	AE Davis, R Rowbottom, LA Schmidt, J Preradovic, KCBS Santos, Rader, R. 2026 Managed fly pollinators ensure berry crop yields under variable weather conditions	Agriculture, Ecosystems & Environment 400, 110254
Scientific publication	J Preradovic, R Rader, BM Dawson, LA Schmidt, R Rowbottom, AE Davis Artificial Pond Habitats Placed in an Australian Berry Farm Support Invertebrate Diversity Including Pollinating Flies	Ecology and Evolution 16 (4), e73423
Grower fact sheets/case studies	Cucurbit and market garden growers in Maitland (n=5) and Western Sydney (n=9) were provided with fact sheets about the pollinators that visit their garden plants	Distributed to individual growers

Outcomes

Table 11. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Development and validation of new management methods to support and improve fly pollination in berries; growers are interested in applying recommended techniques *An understanding of the native insect taxa visitors in cucurbit production systems in the Newcastle area to better inform research into other alternative managed pollinators.* *Determination of the effectiveness of E. tenax as an alternative pollinator of cucurbit crops.* *Determination of the best habitat substrates to promote reproduction of wild pollinators*	Understanding of the impact of different release strategies and identification of optimal timing to ensure high quality berry pollination services Identify optimal farm management practices that mitigate fly losses and improve pollination by flies	Surveys of flower visitor diversity and abundance in cucurbit crops across 11 commercial farms and three market gardens in NSW. Development of fly pollination management strategies for berry and cucurbit crops through polytunnel- and cage-scale research, alongside studies of floral and non-floral habitat enhancement. Validation of these approaches through field-based trials with three commercial berry growers and one commercial cucurbit grower. Industry articles and individual grower communications on the practical application of fly pollination techniques under commercial production conditions. Participating growers increased their understanding of the role of flies as pollinators and the conditions required to support their activity. Growers gained practical knowledge of how and why recommended management practices should be implemented. Engagement in the project resulted in increased confidence and expressed interest in adopting fly pollination strategies.	Research data from 11 commercial cucurbit farms, three market gardens and three commercial berry farms. Findings communicated through industry articles, conference presentations and peer-reviewed journal publications – refer to Outputs table. Media coverage on fly pollination in berry crops, including segments on Landline – refer to Outputs table. Presentation of research findings to commercial growers and industry partners. Observed adoption of fly pollination management practices under commercial conditions. Direct feedback gathered from growers, agronomists and industry extension officers collected through discussions and engagement during the project. Evidence of increased knowledge and awareness from participating growers. Continued provision of trial sites and in-kind support from industry partners and commercial growers.

		The outcome reflects a shift in grower attitudes towards alternative pollination approaches and supports broader industry goals of improving pollination reliability. Adoption of fly pollination methods complements commercial bee pollination inputs and improve pollination consistency, across seasons .	
End-of-project outcomes *Increased awareness of and commitment to adopt best practice of fly pollinator management.* *Actions taken by growers to modify previous management in line with research findings*		Polytunnel-scale fly releases in berry crops across two commercial farms, complemented by cage-level studies and small-scale field releases at a commercial cucurbit farm. Integration of floral and non-floral habitat enhancements on commercial farms to support and sustain fly populations within cropping systems.	Growing interest among producers in NSW in adopting flies as a supplementary pollinator for berry and cucurbit crops, alongside an increasing understanding of its effective use and management.

Monitoring and evaluation

Table 12. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Has the project improved knowledge and awareness of fly pollination in berries?	Yes. We have knowledge of fly performance in pumpkin, zucchini, blackberry, raspberry and blueberry crops. We have also trialled different floral mixes to support pollinators in berry crops and determined that pond habitats support eristaline fly reproduction	The success of this project (and the project PH16002) has led to a new project focused on commercialisation of flies as pollinators.
Has the project developed industry best practice guidelines for fly management on berry farms?	We have not produced guidelines yet as there is still work to undertake to fully understand the use of flies across all of the berry systems. However, we have identified ideal stocking rates for *E. tenax* flies for blackberry crops, have preliminary deployment strategies to mitigate the effects of pesticide sprays on fly survival and we have basic understanding fly dispersal across blocks of blackberry production	
To what extent has the project provided an additional pollination management tool for berry pollination?	We have determined stocking rates in blackberry and appropriate deployment methods.	
Have regular project updates been provided through linkage with the industry communication project?	Project updated industry regularly with meetings, presentations and fact sheets/industry magazine articles. See output list	

Conclusions

This project represents an important step towards developing and validating fly pollination as a practical tool in commercial berry production systems in Australia while highlighting the implications experienced in cucurbit crops. The findings demonstrate that flies can contribute to crop pollination and highlight clear opportunities for adoption, as well as key gaps that require further research, development and extension (RD&E).

Cucurbit Crops

In pollinator surveys of cucurbit crops, flower visitors were dominated by Hymenoptera, with comparatively few flies observed. Our work demonstrated that both *E. tenax* or *E. punctulatus* performed poorly as pollinators of pumpkin and zucchini in both warm and cool-temperate climates or in open field releases. Few observations were made of flies contacting either male or female flowers and flies were progressively dying off in the cages over 3 – 5 day periods. Unfortunately, in this cucurbit crop, flies were not a suitable candidate as alternative managed pollinators. However, research in another project has indicated that E. tenax is an effective pollinator of two melon species. Hence, it is likely fly performance may be crop and/or context specific.

Wild pollinators of cucurbit crops were diverse across different orders but were generally in low numbers. Wild pollinators visited specific co-flowering resources in the presence of cucurbit crops. Wild pollinators generally visited co-flowering plants more frequently than cucurbit flowers during standardised observation periods. This demonstrates that cucurbit flowers are not particularly attractive floral resources. However, native bees, including stingless bees (Tetragonula spp.), sweat bees (Lipotriches and Lasioglossum spp.) and blue-banded bees (Amegilla spp.), regularly visited both co-flowering plants and cucurbit flowers. Basil was particularly attractive to native bees, especially blue-banded bees, which were also among the most frequent visitors to the reproductive parts of cucurbit flowers. In addition to bees, ants were commonly observed visiting cucurbit flowers, particularly pumpkin, where they frequently contacted reproductive structures. Given the low visitation rates of flies to cucurbit flowers, the potential contribution of ants to pollination should not be overlooked and warrants further investigation.

Sunflower attracted the greatest diversity of insects overall and supported a wide range of insects species. However, it also attracted relatively high numbers of true bugs, including the Australian crop mirid (Sidnia kinbergi), which can damage developing flower buds, terminal shoots, and seeds in a wide range of plants (including cucurbits). This demonstrates that co-flowering plants can support both beneficial and pest insects, and that the choice of co-flowering plants must consider potential trade-offs.
For growers, these findings suggest that co-flowering plantings, specifically basil, may help maintain populations of native bees and other flower-visiting insects on-farm, while supporting movement between habitat plantings and crop flowers. Selecting plant species that support key pollinators while minimising pest build-up is likely to provide the greatest benefit to cucurbit production systems

Berry Crops

This project builds upon work in PH16002 that demonstrated that the common drone fly, *Eristalis tenax,* was an effective pollinator blackberry and raspberry plants in small cage and tunnel trials. In the current study, we extended this work on Rubus crops to larger scale poly tunnel (NSW) and open release field trials (Tasmania), and for blackberry, generated data on optimal stocking rates and investigated strategies for deployment and integration into commercial production systems. Furthermore, we extended our work on fly pollination of berry crops to include an initial assessment of the efficacy of Eristalinae flies (*E. tenax* and *E. punctulatus*) as blueberry pollinators and evaluated the potential for habitat augmentation (aquatic pools and floral interrow strips) to promote wild fly pollinators and beneficial insects in berry crops.

Our work has shown that *E. tenax* can function as an effective pollinator of blackberry under commercial conditions, producing fruit comparable in size and quality and, under some conditions, of better size and quality than that achieved within the current (primarily bee-serviced) commercial pollination system. This is a significant finding, given the adverse and expanding impacts of varroa mite on both feral honeybee populations and commercial honeybee pollination services on the Australian mainland, as well as increasing pressures on bee populations globally from a range of pest and environmental factors. Although overall blackberry productivity was lower in winter than in spring, likely due to plant responses to colder temperatures, *E. tenax* provided relatively stronger pollination services under these conditions. Their consistent activity at cooler temperatures suggests that managed flies may be particularly valuable for early spring and winter production cycles.

While use of *E. tenax* as a standalone blackberry pollinator may become feasible as commercial rearing capacity develops, its application as a complimentary managed pollinator is likely to be of greatest short to medium term value. Our work highlights the potential benefits that combined stocking of honeybees and *Eristalis tenax* as managed pollinators could deliver for blackberry growers. This stems from the fact that the two species forage optimally under different environmental conditions. *E. tenax* performs best under cooler conditions, whereas honeybees are most active under warmer conditions. Furthermore, as *E. tenax* can be deployed directly into berry tunnels, they are able to service the crop when honeybees are less likely to leave their hives for example for example on windy days or during periods of rainfall. In this way, complimentary stocking of both species may extend the range of conditions under which blackberries are effectively pollinated, and this could improve fruit yield and quality outcomes for growers.

In enclosed tunnel trials with *E. tenax* as the sole pollinator, fruit weight was optimised when foraging activity during the main bloom period was 2 to 3 flies/m. Previous research in PH16002 has shown that the pollination efficiency of individual *E. tenax* and honeybees visiting blackberry flowers is approximately equivalent, so this information may not only provide a target activity level for stocking of *E. tenax* as a stand-alone pollinator but also a starting point for studies investigating complimentary stocking of *E. tenax* and honeybees into blackberry crops.

As flies remain within the crop at night, they are potentially more vulnerable to adverse effects from pesticide applications than honeybees, which return to the hive. In tunnel and open release trials, we observed varying impacts of different insecticide and fungicide applications of fly population dynamics and this was supported by laboratory assays that showed varying degrees of toxicity to *E. tenax* between different fungicides and insecticides, even amongst different products targeting similar pests. In addition to fly losses from pesticide application, natural mortality and, in open releases, migration of flies away from the target crop also led to progressive declines in fly pollinator populations over time. We observed that a fly release strategy involving up to 4 releases of pupae at 7- to 10-day intervals from before until the end of the main bloom period was effective in maintaining fly numbers within the crop during flowering. Additionally, careful selection of crop protection products to minimize impacts on *E. tenax* (where more than one permitted product option exists) and use of critical control thresholds in preference to preventative or calendar-based pesticide applications will assist with effective deployment of *E. tenax* in berry crops.

Work on blackberries in this project concluded with the first, semi-commercial scale open release of *E. tenax* as a managed pollinator of blackberry tunnels in Tasmania, where 150,000 pupae were released over 3 weeks into 1.7ha of blackberry tunnels. We observed that *E. tenax* effectively spread from pupal deployments in a central block of tunnels into adjacent tunnel blocks, and that a significant proportion of the flies generated from the deployments were retained within the crop during flowering. While the trial was also stocked with managed honeybees and subject to commercial pest management regimes, *E. tenax* accounted for between 46 and 62% of pollinators observed foraging on flowers during the main period of bloom. Learnings from this experiment can inform fly deployment strategies in future studies aimed at more extensively developing and testing open deployment of *E. tenax* and evaluating the commercial benefit of mixed pollinator stockings (*E. tenax* and honeybees) in blackberry crops across different production regions

Although *E. tenax* can effectively pollinate raspberry in cage trials (Davis, et al. 2026), our attempt at an enclosed tunnel level trial during winter on the NSW mid-north coast had to end prematurely due to impacts of the enclosed tunnel environment on plant health from an accumulation of nectar, which led to mould development on the fruit. Raspberries have been observed to typically produce larger volumes of nectar than blackberries in commercial production and in other research (Schmidt et al., 2026). While it is likely that this problem could be addressed through use of higher stocking rates of *E. tenax* in raspberry crops, a better strategy for future raspberry pollination trials may be to focus on combined stockings of *E. tenax* and honeybees to exploit the complimentary foraging patterns of the two species (ie. potentially improved pollination under cooler conditions, coupled with the capacity of honeybees to pollinate effectively and utilize the larger volumes of nectar produced under more favourable conditions). As raspberries are produced year-round in some regions, future research on fly pollinators should also consider the most appropriate species for crops that flower under warmer, summertime conditions, where *E. tenax* may be less effective. A potential candidate is the related Australian native hoverfly species, the golden drone fly (*Eristalinus punctulatus*). This wild pollinator occupies the same ecological niche as *E. tenax*, is known to visit berry crops (Davis, et al 2022) and is well suited to mass production using the same rearing protocols as *E. tenax*, but has a spatial and temporal distribution based around warmer climatic conditions (Cook et al., 2020).

In cage trials, both *E. tenax* and the Australian native golden drone fly (*Eristalinus punctulatus*) were capable of pollinating 'Snowchaser' blueberries, resulting in fruit that was substantially heavier than that produced by flowers excluded from insect pollinators. Although pollinator foraging activity was greatest in cages stocked with *E. tenax*, average fruit weight from open pollinated blocks, where honeybees were the predominant pollinator, was heavier than from caged plots pollinated by *E. tenax* and *E. punctulatus* respectively. Future studies to refine deployment of these species as blueberry pollinators should consider whether performance can be improved by varying stocking rates, assess suitability of the species across different cultivars, and evaluate the potential advantages of complimentary stocking with other managed pollinators.

In addition to the potential for flies to be developed as managed berry crop pollinators, berry growers may be able to proactively promote wild populations of beneficial insects including pollinators on their farms through the adoption of habitat augmentation measures to support the nutritional and lifecycle requirements of these insects. In this project, we have shown that artificial habitat ponds incorporating plant organic matter promoted reproduction of wild hoverfly and other species known to contribute to crop pollination by providing oviposition sites and supporting development of their aquatic larval stages. In addition to supporting hoverflies, the habitat ponds attracted a wide range of beneficial insects that can help suppress crop pests and break down organic matter, contributing to nutrient cycling within the farm environment. Some pest species were also present, highlighting the importance of monitoring pond conditions over time. The extent to which these communities could contribute to ecosystem services within adjacent crops remains unclear as yet, with further research required to establish whether invertebrates developing within ponds move into crop areas and provide measurable benefits such as pollination or pest suppression.

Recommendations for Growers and Industry (Practical Application)

Cucurbit crops

- Establish and maintain habitats that provide nesting opportunities, nectar and pollen resources, and sites for pollinators to reproduce to encourage reliable wild pollinator populations

Rubus crops

- Growers should consider incorporating flies as a supplementary pollination strategy, particularly in protected cropping systems such as polytunnels where fly retention and activity can be optimised.
- Enhancing floral and non-floral resources within and around production systems is recommended to support fly activity and persistence.
- Growers should aim to maximise pollinator activity during flowering, as repeated visitation by flies is likely to improve fruit set and quality.
- Small-scale, on-farm trials are recommended to refine implementation approaches under individual production conditions.
- Consider establishing aquatic habitats where appropriate, as they can provide important breeding and refuge sites for Eristaline flies and other beneficial insects

Recommendations for Future Research, Development and Extension

- Other managed pollinators such as other native bees or flies may be worth investigating as alternative pollinators in cucurbit crops
- Development of crop-specific deployment strategies are needed, including optimal stocking rates, release timing and approaches for maximising fly retention and effectiveness.

- Additional work is required to better understand fly behaviour, movement and persistence in open-field versus protected cropping systems.
- Incorporation of other commonly used pesticides and fungicides used by industry impact fly pollinators to understand how best to integrate managed pollinators into existing crop management practices.
- Further investigation is warranted for key fly species identified in this project, as well as other potential pollinators, to continue to improve diversity of other managed pollinators available for use in horticulture and broaden application across crops and regions.
- Economic analyses are needed to assess the cost-benefit and adoption potential of fly pollination for commercial growers.
- Given the season and plant conditions in this trial it is recommended to revisit fly pollinator performance, particularly future trials evaluating stocking rates of managed flies on blueberry cultivars which would inform open release strategies.
- Investigations into seasonal variation in fly pollinator performance in blueberries is warranted, particularly in warmer growing conditions which may benefit *E. punctulatus* activity and performance
- Continued extension is required to translate project findings into practice, including on-farm demonstrations, field days and grower engagement activities.
- Development of clear, practical guidelines for implementation of managed fly pollination strategies in berry crops to support adoption.
- Ongoing collaboration between researchers, growers, agronomists and industry bodies will be critical to refining and validating management practices.
- Efforts should be made to build industry awareness and acceptance of flies as pollinators, including addressing any misconceptions.

Overall, this project has demonstrated growing industry interest and increasing capability to adopt fly pollination strategies. With continued RD&E and targeted extension, fly pollination has strong potential to improve pollination reliability, reduce risk, and enhance productivity in Australian horticultural systems.

Refereed scientific publications

Journal article

Preradovic J, Rader R, Dawson BM, Schmidt LA, Rowbottom R, Davis AE, 2026. Artificial pond habitats placed in an Australian berry farm support invertebrate diversity including pollinating flies. Ecology and Evolution 16(4): e73423. https://doi.org/10.1002/ece3.73423.

Davis AE, Rowbottom R, Schmidt LA, Preradovic J, Santos KCBS, Dawson B, Manrique M, Wright D, Shermeister B, Hocking B, Branco J, Rocchetti M, Spurr C, Rader R, 2026. Managed fly pollinators ensure berry crop yields under variable weather conditions. Agriculture, Ecosystems & Environment 400(110254). https://doi.org/10.1016/j.agee.2026.110254.

AE Davis, LA Schmidt, KCBS Santos, L Martin, S Harrington, M Rocchetti, Rader, R. (2022). The golden native drone fly (Eristalinus punctulatus) is an effective hybrid carrot pollinator that lives within Australian crop agroecosystems. Ecological Solutions and Evidence 4 (4), e1229

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Intellectual property

No project IP or commercialisation to report

Acknowledgements

We would like to acknowledge Costa for the use of their field sites in the Coffs Harbour region, in particular to Brad Hocking, Derek White, Bar Shermeister and Joaos Branco for their assistance in trial set up and implementation. To the independent growers; Justin Hundle and Gary Atwal for access to their production tunnels for trials and to Matthew Denis at Nebo Farms for providing access to his farm to conduct cucurbit trials.