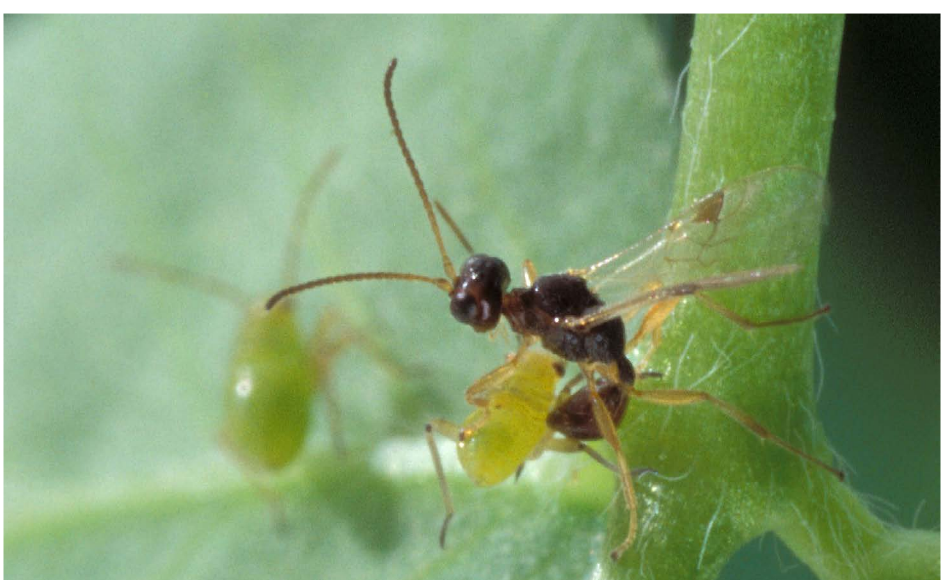
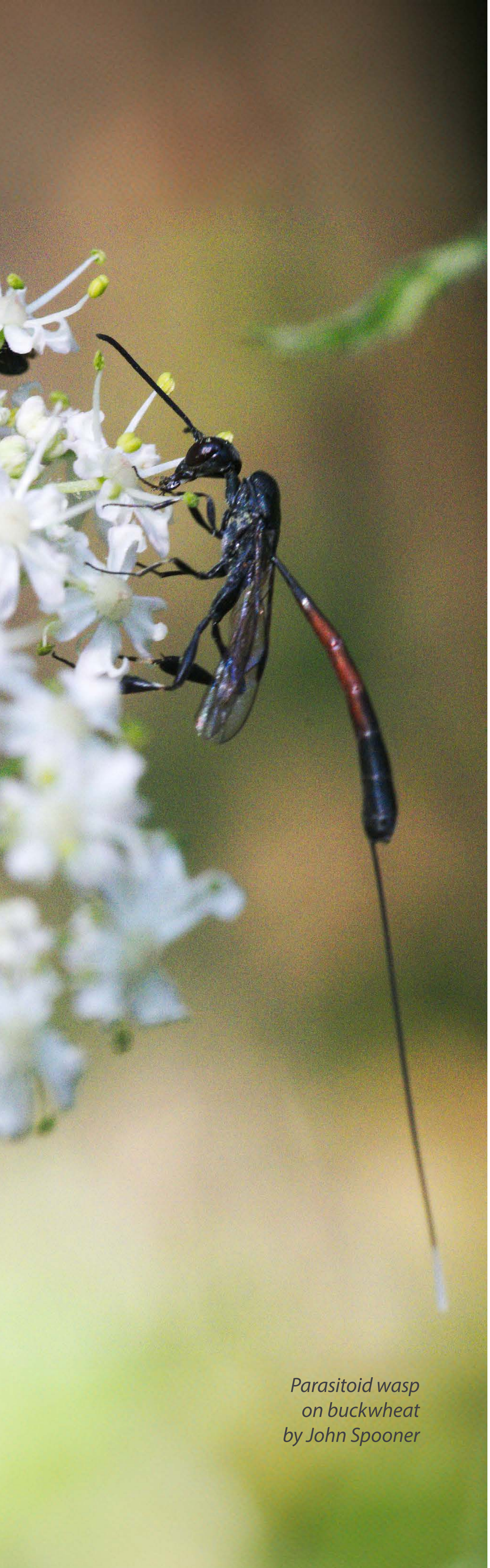
MANAGING PESTS

With Predator & Parasitoid Habitat



WILD FARM ALLIANCE

Publication Excerpt



Parasitoid wasp on buckwheat by John Spooner

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ABOUT WILD FARM ALLIANCE

Our mission is to promote healthy, viable agriculture that protects and restores wild nature. We strive for a world in which community-based, ecologically managed farms and ranches are seamlessly integrated into landscapes that accommodate a range of native species and ecological processes. WFA was established by a national group of wildlands proponents and ecological farming advocates who share a common concern for the land and its inhabitants. For more than 23 years, we have been a leading voice for the bridge between the conservation of wild nature and the sustainability of farming systems. Our work is centered on engaging and empowering those involved in the food and farming movement, including everyone from farmers and conservationist to certifiers and consumers, and since our inception we have led on-farm biodiversity conservation practice, education and policy. We have deep in-house expertise and a robust network of partners and collaborators to help Bring Nature Back to the Farm.

Additional Resources from Wild Farm Alliance can be found at:
www.wildfarmalliance.org/resources

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COVER PHOTOS: *Syrphid Fly on sweet alyssum by TJ Gehling, Lacewing larva eating mites by Joe Lapp, Minute Pirate Bug feeding on Whitefly nymphs by Jack Dykinga, parasitoid wasp laying eggs in aphid by Scott Bauer*

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Please note, this is an excerpt of a longer publication that will include 10 of the major crops grown on the West Coast. The longer publication will be released in spring 2024.

Lacewing larva

Phacelia flower strip
Photo: Tom Hilton

INTRODUCTION

Excerpted from a larger document covering 10 of the major crops grown on the West Coast, this selection of accounts shows how habitat can help growers better integrate lasting solutions into their pest management regimes. Farmscaping with habitat for natural enemy predators and parasitoids can save on input costs. When managing with other cultural practices that keep crops healthy and don't encourage pests, growers can get off the pesticide treadmill while bringing nature back to the farm.

In writing the crop accounts, we emphasized the main insect pests of these crops in organic or sustainable production, the natural enemies that attack them, and the habitat that supports these beneficials. We purposely omitted the secondary pests that come with the use of broad-spectrum insecticides.

Farms that have a multitude of niches for natural enemies will support a blanket of attack. These beneficials have different ways to attack pests at different times in the season and in different places in the farm environment. Beneficial arthropods, which include insect predators and parasitoids, spiders and predatory mites, need food, water and shelter to survive. Large beneficials like Lacewings can fly to where the pests are located and lay eggs, and their emerging larvae consume the adults and eggs of prey species. Wasp parasitoids can be large or small with variable ability to disperse. Adults fly to pest eggs or larvae and attach or insert their offspring into their hosts, which are then slowly consumed as the parasitoids mature. Web-building spiders catch pests flying by. Smaller organisms like predaceous mites need continuous cover to move far; otherwise conditions such as hot, dry fields and roads are too harsh for them to cross. Ground predators, such as predaceous ground beetles and Wolf Spiders (which typically stalk and pounce on ground pests, hence their name "wolf,") benefit from no till or low till operations that provide shelter in the form of vegetation and crop debris. In a more simplified monocultural system, where there are limited niches and only a couple of beneficials present besides the crop pest, the larger beneficial may be compelled to eat the smaller beneficials because the food sources are so limited.

Coyote brush. Photo: Melissa McMasters

Having year-round habitat for natural enemies means they will be around when pest populations start to build in the spring. Sequentially flowering native plant hedgerows and other field buffers and patches can provide floral resources and more favorable microclimates in every season. Selecting some of those plant species to have flower characteristics favorable for small parasitoids ensures the insects' longevity and increases their reproductive capacity. Additionally, certain plants provide more benefits. Coyote brush (*Baccharis pilularis*), which is a commonly used plant in hedgerows, supports an alternate, non-pest prey host for wasp parasitoids when pests aren't available. Peppers, which have soft hairless surfaces, provide Minute Pirate Bugs with easily punctured plant tissue where they can lay their eggs.

Natural enemies, especially the larger ones, will move 250 to 300 feet from a hedgerow into the crop. The smaller ones move less, so interspersing annual plants such as sweet alyssum, coriander and dill with the crop will draw beneficials into the crop where they can do the most good.

Associations between pollinators and the flowering plant they use are straightforward in that pollinators drink the nectar, which provides sugars for energy, and use both the pollen and nectar for reproduction. Natural enemy arthropods utilize the flowering resources similarly. However, what else they need and how farmers can support them and repel the pests is a more complex and fascinating story of their relationship.

More to come …

AVOCADO PESTS:
NATURAL ENEMIES & THEIR HABITAT

AVOCADO THRIPS (*Scirtothrips perseae*) are a major pest in avocado production. This insect was introduced into California from Mexico and was first found in Ventura in 1996 (Hoddle and Morse 1999). The larvae feed on young fruit and cause scarring. As the avocado grows, the scarring expands, creating "alligator skin" which results in the fruit to be down-graded at the packinghouse. The damaged skin can be so brittle that it is often rejected by the packing-house. Avocado Thrips can be active year-round in the mild coastal climates of California's growing areas. Peak egg laying occurs in the spring when young leaves and fruit are present and the temperature is about 67˚ F (Morse et al. 2016).

- The main predators of Avocado Thrips larvae and adults found in California are phytoseid mites, mostly *Euseius hibisci*, which are specialized pollen feeders; spiders (Araneae); and the predatory thrips *Franklinothrips orizabensis* and *Aeolothrips kuwanaii*. Other generalist predators include additional species of predatory thrips and Green Lacewings (Chrysopidae) (Yee et al. 2001; Hoddle and Morse 2003).
- Pollen from avocado, olive and corn (González-Fernández et al. 2009) elevate populations of predatory mites, especially *Euseius spp.* (Montserrat et al. 2013). Plants that promote a diversity of prey within the grove may help to keep beneficial arthropod populations elevated by providing alternate prey if the populations of primary avocado pests are low. The presence of pollen can also help to reduce intraguild predation between predatory mites (Montserrat et al. 2013).
- Avocado Thrips spend time in the leaf litter, as do predatory thrips (Yee et al. 2001). Keeping a thick layer of leaf duff and applied mulch on the grove floor, especially under the trees, provides habitat for predatory thrips, spiders, ground-dwelling predacious mites, beetles and nematodes that feed on the prepupal and pupal stages of Avocado Thrips (Yee et al. 2001; Hoddle and Morse 2003).

Leaf litter on the grove floor provides habitat for predatory thrips, spiders and other natural enemies. Photo: King & King Ranch

Predatory mite feeding on pest mite.
Photo: International Institute of Tropical Agriculture

PERSEA MITES (*Oligonychus perseae*)are a major pest in avocado production. These spider mites were introduced from Mexico and first identified in San Diego County in 1990. Heavy feeding by Persea Mites can cause defoliation and sunburn of fruit and bark and can reduce productivity.

- Both predatory mites *Galendromus helveolus* and *Neoseiulus californicus*, either alone or in combination, significantly reduced numbers of Persea Mite in comparison to oil-sprayed trees and control trees where nothing was sprayed (Kerguelen and Hoddle 1999).
- Two other species of predatory mites, *Euseius hibisci* and *E. stipulates*, along with *N. californicus*, feed on both Persea Mites and pollen. *N. californicus* is especially adapted to break into Persea Mite nest webbing and consume both eggs and adult females, which *Euseius* mites are unable to do (Montserrat et al. 2013). Of minor importance are the predaceous mites *Galendromus annectens* and *G. helveolus* (Morse et al. 2016).
- Many other predators will consume the Persea Mites, including Black Hunter Thrips (*Leptothrips mali*), Sixspotted Thrips (*Scolothrips sexmaculatus*), Brown Lacewings (Hemerobiidae), Green Lacewings (Chrysopidae), Dustywings (Coniopterygidae), predatory midges (*Feltiella sp.*), Rove Beetles (*Oligota oviformis*) and Spider Mite Destroyer Lady Beetles (*Stethorus picipes*). Because of Persea Mites' protective webbed nests, most of the above-mentioned predators are not highly effective (Morse et al. 2016).
- Pollen produced by corn has been shown to enhance the survival and reproduction of the predatory mites, and in-field planting between trees may be compatible within commercial avocado production groves (Eini et al. 2022; González-Fernández et al. 2009). To provide an overlapping pollen supply, different varieties of corn that bloom at different times can be planted, or the same variety of corn can be planted at different times to provide the same effect.

BRASSICA PESTS:
NATURAL ENEMIES & THEIR HABITAT

APHIDS: Cabbage Aphids (Brevicoryne brassicae) cause devigoration of new transplants and infest leaves and florets, which can render the produce unmarketable. They overwinter as nymphs or adults in temperate climates. Green Peach Aphid (*Myzus persicae)* and Turnip Aphid (*Lipaphis erysimi)* cause stunting in bok choy and Napa cabbage.

- A diverse set of predators, including Green Lacewings (Chrysopidae) and Brown Lacewings (Hemerobiidae), Syrphid Flies (Syrphidae), Lady Beetles (Coccinelidae) and Minute Pirate Bugs (*Orius spp*.) help control aphids. Lacewings preferred lacy phacelia (*Phacelia tanacetifolia*) in flower strips containing several species located in cabbage fields, and fewer pests were present next to these strips (Alcalá Herrera et al. 2022). Syrphid Fly biocontrol of aphids in broccoli crops is enhanced when sweet alyssum is intercropped with it (*Lobularia maritima*) (Brennan 2016).
- *Hymenoptera* wasps parasitized a higher percent of aphids, and more Syrphid Fly eggs were on the crop leaves in broccoli interspersed with sweet alyssum (*Lobularia maritima*) rather than with cilantro (*Coriandrum sativum*). In other broccoli plots, cilantro was highly attractive to Syrphid Flies, and mustard (*Brassica juncea*), annual buckwheat (*Fagopyrum esculentum*) and Korean licorice mint (*Agastache rugosa*) were most attractive to *Hymenoptera* (Colley 1998).
- Hedgerows containing common yarrow (*Achillea millefolium*) were attractive to hemipteran predators Big-eyed Bugs (*Geocoris*), Damsel Bugs (*Nabis sp.*) and Minute Pirate Bugs; coffeeberry (*Rhamnus californica*) to Lacewings; and perennial buckwheat (*Eriogonum giganteum*) and California lilac (*Ceanothus griseus* and *C. 'Ray Hartman'*) to Syrphid Flies. Toyon (*Heteromeles arbutifolia*) was used by several of these insect groups and Lady Bugs in the summer when other plants were not blooming as much (Pisani Gareau and Shennan 2010).
- The parasitoid wasp *Diaeretiella rapae* will use the extrafloral nectaries of broad beans (*Vicia faba*) to extend their ovipositional (egg-laying) period (Jamont et al. 2013). Many flowering species, such as coriander (*Corriandrum sativum*), are shown to be highly attractive to parasitoid wasps, and others such as annual buckwheat (*Fagopyrum esculentum*) that are not as attractive greatly promote parasitoid longevity (Russell 2015). Coyote brush (*Baccharis pilularis*) in hedgerows was attractive to parasitoid wasps (Pisani Gareau and Shennan 2010). Growing several plant species in combination can ensure many beneficial qualities are present.
- Supporting predators and parasitoids with multiple plant resources within the same area increases the complexity of the prey available and reduces intraguild predation (natural enemies killing one another) (Snyder 2019).

Parasitoid wasp and aphids
Photo: Scott Sherrill-Mix

Minute Pirate Bug with thrip
Photo: Gary Chang

THRIPS: Onion Thrips (*Thrips tabaci*) and Western Flower Thrips (*Frankliniella occidentalis*) are significant pests of brassica crops. Feeding injury consists of rough surfaces, sunken leaf tissue and considerable discoloration.

- Minute Pirate Bugs (*Orius spp.*) are primary predators of thrips larvae. Plantings of annual buckwheat (*Fagopyrum esculentum*) and cowpea (*Vigna unguiculata*) provide nectar and pollen, as well as suitable plant tissue for laying their eggs (Hinds and Barbercheck, 2020). The flowers and plant tissue of sweet alyssum (Pumariño and Alomar 2012), coriander (*Coriandrum sativum*) and marigold (*Tagetes sp.*) are also used by Minute Pirate Bugs (Zhang et al. 2021).
- Rove Beetles (Staphylinidae) (Li et al. 2020), entomopathogenic fungi (Sánchez-Peña et al. 2011) and nematodes (Lim et al. 2001; Gulzar et al. 2021) attack thrips in the soil during their vulnerable, nonmotile pupal stage. These beneficials are found in many healthy soil ecosystems (Whitehurst and Dietrick 2024).
- Predatory mites can also feed on thrips eggs while still embedded in the plant tissue and on early larval stages of thrips. Two of the mites studied for thrips control, *Amblyseius largoensis* and *Amblyseius swirskii,* reduced thrips hatching up to 30% (Nguyen et al. 2019), and the latter is commercially available (Whitehurst and Dietrick 2024).
- One of the best ways to reduce thrips damage to brassica crops is to plant resistant varieties; work is ongoing to find those mechanisms of resistance (Shelton et al. 2008, Stoner and Shelton 1988).

FLEA BEETLES: Western Flea Beetle (*Phyllotreta pusilla)*, Crucifer Flea Beetle (*P. cruciferae*), Striped Flea Beetle (*P. striolata*) and Cabbage Stem Flea Beetle (*Psylliodes chrysocephala)* are significant pests in brassica species, especially on seedlings and those species with thinner leaf tissue (Terrick 2024) and can render the crop unmarketable. The most common damage is called "shothole" damage to leaves. Flea beetle are very difficult to control due to their high mobility. Flea beetle larval stages usually occur underground, and adults move up to feed on foliage when weather warms (Cranshaw 2019).

- The most significant parasitoid wasp of Flea Beetles in North America is *Microctonus vittatae*. Up to 53% of the emerging adult Crucifer Flea Beetles were parasitized early in the season, whereas the parasitism of the Striped Flea Beetle was only up to 15% (Wylie 1982). This wasp will likely benefit from the same plant species that other parasitoid species use.
- The Carabid Beetle, *Trechus quadristriatus*, was found to be a significant predator of the eggs and larvae of Cabbage Stem Flea Beetle (Hoarau et al. 2022). This research occurred in Europe, but similar carabid beetle species may be present in North America.
- In oilseed rape fields, about 20% of Wolf Spiders (*Pardosa*) and about 10% of Cobweb Spiders (*Phylloneta impressa*) that were collected had eaten Flea Beetles (Ekbom et al. 2014). Farms with a variety of habitats that provide a diversity of food sources, shelter sites, web attachment sites and microclimatic features will support more spiders and their predation (Maloney et al. 2003).

- Some of the main biocontrol techniques being researched for addressing Flea Beetles in crop protection are the use of entomopathogenic nematodes and entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* (Hoarau et al. 2022), which are found in many healthy soil ecosystems.
- Trap crops have a significant potential to aid in the control of Flea Beetles by intercepting adults before they get to the cash crop (Scagliarini et al 2023; George et al 2019). Leaving a space of at least 2 meters of bare ground between the trap crop and the cash crop can increase the effectiveness of the trap crop (Scagliarini et al 2023).
  Turnip rape (*Brassica rapa, var. Pasja*) has been proposed as a potential trap crop for Flea Beetles next to brassica fields (George et al. 2019).

LEPIDOPTERAN PESTS (caterpillars) can cause significant losses in brassica crops. They feed on new transplants and the leaves of older plants, and they burrow into the plant tissue, causing unseen damage. Diamondback Moth (DBM) (*Plutella xylostella*) is the most significant lepidopteran pest of brassica crops. It has multiple generations per year, which allow for rapid resistance to many pesticides used in its control, including *Bacillus thuringiensis* (*Bt*) pesticides (Talekar and Shelton 1993). DBM are known to be able to migrate over 1,800 miles in continuous flight for several days via wind currents (Chu 1986). Migration of its parasitoids is hypothesized to occur via the same routes (Talekar and Shelton 1993).

Syrphid fly on yellow rocketcress. Photo: TJ Gehling

- DBM damage can be reduced by planting a "dead-end trap crop," which is a plant that is highly attractive to the pest, but on which the pest cannot successfully complete its development (Badenes-Pérez et al. 2014). The plant species best used for a DBM dead-end trap crop program is yellow rocketcress (*Barbarea vulgaris var. arcuata*, type-G). The type-G variety has a glabrous (smooth) leaf surface as opposed to a pubescent (hairy) leaf surface common in other Barbarea species. Type-G produces volatile compounds that are highly attractive to ovipositing (egg-laying) female DBM. When DBM larvae feed upon the plant, it produces internal saponin compounds that cause the larvae to cease feeding on it and results in their death (Badenes-Pérez et al. 2017). Since yellow rocketcress type-G is a biennial species, it can be allowed to bloom in the second year, providing floral resources for natural enemies (Idris and Grafius 1995; Munir et al. 2015). Yellow rocketcress was found to be among the best plants to promote the longevity of parasitoid wasps in general (Russell 2015). It is an excellent salad crop that regenerates rapidly when harvested, which make makes it possible to grow this species as a cash crop for salad mix operations (Badenes-Pérez 2011).
- Plants that greatly support the wasp parasitoid *Diadegma insulare*, but not DBM, are sweet alyssum (*Lobularia maritima*) (Munir et al. 2018; Johanowicz 2000), and the mix of annual buckwheat (*Fagopyrum esculentum*) and lacy phacelia (*Phacelia tanacetifolia*) (Lavandero et al. 2006).
- Cover crop residue of hairy vetch (*Vicia villosa*) and winter rye (*Secale cereale*) mowed and left behind in brassica fields decreased DBM larvae (*Plutella xylostella*) and cabbage maggot egg (*Delia radicum*) infestation at one site and increased slugs at another (Mangan et al. 1995).
- Parasitoid species (tachinid flies, ichneumon wasps, braconid wasps) were positively associated with the amount of riparian and other natural vegetation in 1,600 feet surrounding broccoli, kale and cauliflower fields (Letourneau et al. 2015).

Parasitoid wasp (Scoliidae) on cornflower
Photo: TD Lucas

Other lepidopteran pests of brassicas include Cabbage Looper (*Trichoplusia ni*), Cabbage Butterfly (*Pieris rapae*), Beet Armyworm (*Spodoptera exigua*) and cutworms.

- Many parasitoid wasps attack caterpillars. The lifespan of one wasp species increased significantly when feeding on annual buckwheat (*Fagopyrum sagittatum*), somewhat less when on licorice mint (*Agastache foeniculum*) and less on sweet alyssum (*Lobularia maritima*) (Nafziger and Fadamiro 2011).
- The presence of *Ichneumonidae* parasitoids, which killed Cabbage Looper, was influenced by *Baccharis* shrubs (Bothwell 2012).
- Tachinid flies (Tachinidae) can also reduce the populations of lepidopteran larvae (Scaramozzino et al. 2020).
- Planting cornflowers (*Centaurea cyanus*), which have extrafloral nectaries, in cabbage fields significantly increased parasitism and predation of a moth, which reduced crop damage (Balmar et al. 2014).
- *Trichogramma* parasitoid wasps attack caterpillars and are available commercially (Whitehurst and Dietrick 2024).
- Lacewings, Syrphid Flies, and Minute Pirate Bugs will attack many kinds of caterpillars (Lee-Mäder et al. 2014).

BAGRADA BUGS (*Bagrada hilaris*) are invasive stink bugs that have become significant pests of brassica crops in California. Adults and nymphs feed on all plant parts. Damage can include disfiguration, stunting and death of young plants as well as inducing multiple head formation on more mature plants. Bagrada Bugs also impact other crops in the families Solanaceae, Fabaceae, Poaceae, Malvaceae, Amaranthaceae, Cucurbitaceae and Apiaceae. Eggs are laid in the ground near host crops.

- The Asian wasp parasitoid *Gryon aetherium* attacks the eggs of Bagrada Bugs (Hogg et al. 2021). Two other wasp parasitoids of Bagrada Bug eggs are currently being studied, both species in the genus *Ooencyrtus*; one is from Pakistan and the other, from California. The latter is believed to prefer Bagrada Bugs over a native Stink Bug host (Triapitsyn 2020). Parasitoid wasps benefit from flowers with highly available nectar resources in the Apiaceae, Polygonaceae, and Brassicaceae families (Russell 2015).
- Entomopathogenic nematodes have also been found to be a somewhat effective control of Bagrada Bugs with parasitism rates approaching 60% on arugula plants (*Eruca sativa*) in semi-field studies (Lankin et al. 2022).

CITRUS PESTS:
NATURAL ENEMIES & THEIR HABITAT

ASIAN CITRUS PSYLLID (ACP) (*Diaphorina citri*) vectors the bacterium *Candidatus liberibacter asiaticus*, which causes the citrus disease Huanglongbing that kills trees (Milosavljević et al. 2017).

- The two main parasitoid wasps of ACP in California are *Tamarixia radiata*, which lays its eggs on the outside of ACP nymphs, and *Diaphorencyrtus aligarhensis*, which lays its eggs inside the nymphs; both were imported from Pakistan. Besides killing the nymphs through parasitism, the adults of these two wasps feed from the nymphs' hemolymph (analogous to insect blood) after stinging them. These parasitoids complement each other due to their preference for attacking different stages of ACP nymphs (Milosavljević et al. 2017). Annual buckwheat (*Fagopyrum esculentum*) and sweet alyssum (*Lobularia maritima*) have been shown to be among the best plants for the promotion of longevity of parasitoid wasps in general (Russell 2015).
- Syrphid Fly (Syrphidae) larvae have a substantial impact of reducing ACP populations (Milosavljević et al. 2017; Irvin et al. 2021). Sweet alyssum significantly increased the number of Syrphid Fly eggs laid in ACP colonies by 350% and the number of predatory mites and Lacewings by 250%. Annual buckwheat (Irvin and Hoddle 2021) and California lilac (*Ceanothus spp.*) (Pisani Gareau and Shennan 2010) also increases Syrphid Fly presence.
- Lady Beetles (Coccinellidae), Green Lacewings (Chrysopidae) and Brown Lacewings (Hemerobiidae) and hunting spiders (Aranae) add to the complex of ADP predators (Michaud 2002). The incorporation of a diversity of plant species within the citrus groves may enhance the predator biocontrol.
- In Florida, primary sources of mortality for ACP nymphs are two coccinellid species, the Ashy Gray Lady Beetle (*Olla v-nigrum*) and the Multicolored Asian Lady Beetle (*Harmonia axyridis*) (Michaud 2002). Both are known to be in California and may help with ACP control.
- Spiders living within the tree canopy are very important predators of ACP in citrus groves that are not using broad spectrum pesticides. Assassin bugs (Reduviidae), Dustywings (Coniopterygidae), and omnivorous earwigs (Forficulidae) are also important predators (Walther 2024).
- Control of Argentine Ants (*Linepithema humile*), which tend and protect ACP nymphs, can greatly increase the efficacy of biocontrol programs. *Tamarixia radiata* has successfully established in California, and between it and mainly Syrphid Flies, the densities of ACP have decreased approximately 70% (Hoddle et al. 2022).

Mummified Asian citrus psyllids, Diaphorina citri, with exit holes of a parasitic wasp, Tamarixia radiata. Credit: Mark Hoddle

SCALE INSECTS: California Red Scale (CRS) (*Aonidiella aurantii*), Citricola Scale (*Coccus pseudomagnoliarum),* Brown Soft Scale (*Coccus hesperidum*) and Black Scale (*Saissetia oleae)* cause damage to citrus by sucking sap from the phloem and generally devigorating the plants. This devigoration can cause leaf wilt and fruit drop and in severe infestations can result in tree death. When considering biocontrol of scale pests in citrus, the coastal and southern California regions must be treated separately from the San Joaquin Valley (SJV). If insect growth regulators or broad-spectrum pesticides are used to manage these pests, the beneficial parasitoids and predators will be affected as well.

- The major wasp parasitoids of California Red Scale are *Aphytis melinus*, *Aphytis lingnanensis*, *Comperiella bifasciata* and *Encarsia perniciosi* (Sorribas and Garcia-Mari 2010). The standard procedure for the control of CRS in California is the release of commercially reared *Aphytis melinus* at periods when Insect Growth Regulators (IGR) will not interfere with the life cycle of the parasitoid. *A. melinus* predominantly feeds on honeydew and hemolymph after attacking it. Honeydew and sugar resources increase wasp longevity, and nutrients improve egg maturation (Heimpel et al. 1997).
- The Lady Beetle (*Rhyzobius lophantae*) and the larvae of the fly *Lestodiplosis aonidiellae* also attack CRS (Sorribas and Garcia-Mari 2010).
- Citricola Scale, Black Scale and Brown Soft Scale are controlled well by wasp parasitoids such a *Metaphycus helvolus*, *M. luteolus*, *M. stanleyi* and *Coccophagus semicircularis* in the coastal and southern California regions (Bernal et al. 2001).
- However, Citricola Scale is the most serious pest impediment to development of effective biocontrol programs in SJV citrus. The summer heat and winter cold have altered the development of the Citricola Scale stages so that there are significant periods of time when the second instar scale stages needed for parasitism by *Metaphycus* and *Coccophagus* parasitoids are not available (Bernal 2001). Brown Soft Scale and Black Scale mentioned above have multiple generations per year and serve as alternate hosts for these parasitoids but they are not present in many areas of the SJV due to the environmental extremes.
- Spiders, Assassin Bugs, Dustywings and omnivorous earwigs are also important predators (Walther 2024).

MEALYBUGS: Citrus Mealybugs (*Pseudococcus citri)* and Longtailed Mealybugs (*Pseudococcus longispinus*) damage citrus by feeding on phloem, causing devigoration of the trees, and also cosmetic damage through the production of honeydew, leading to the growth of sooty mold on the excess honeydew.

- The coccinellid beetle, *Cryptolaemus montrouzieri*, is one of the main biocontrol agents of mealybugs in citrus (Gaines et al. 2022).
- Green Lacewing larvae and wandering spiders can also be significant predators of mealybugs in citrus (Gaines et al. 2022).
- The parasitoid wasp, *Anagyrus pseudococci, is an*other important biocontrol species. *Availability of nectar resources from annual buckwheat flowers and* cahaba vetch (*Vicia sativa*) extrafloral nectaries can increase the offspring production of *Anagyrus* wasps by up to 152%. Buckwheat also increased the percentage of *Anagyrus* female offspring by up to 15% (Irvin and Hoddle 2015).
- Assassin bugs, Dustywings, earwigs and spiders also attack mealybugs (Walther 2024).

Coccinellid beetle larva eating mealybug nymphs
Photo: Dr. Guido Bohne


Ants tending Citrus mealybug
Photo: Katja Schulz

ARGENTINE ANTS (*Linepithema humile*) herd honeydew-producing insects such as scale, aphids, mealybugs and Asian Citrus Psyllids for food, and in doing so, reduce biocontrol efficacy.

- The control of Argentine Ants is critical to the implementation of biocontrol programs addressing honeydew-producing pests (Milosavljević 2017).

THRIPS: Citrus Thrips (*Scirtothrips citri*), Greenhouse Thrips (*Heliothrips haemorrhoidalis) and* Bean Thrips (*Caliothrips fasciatus*) cause scaring on fruit that downgrades the fruit at the packinghouse.

- The mite *Euseius tularensis* is a prominent predator of thrips in the larval stage on citrus leaves and the pupal stages in the soil. The presence of ground cover and the availability of airborne pollen resources supports predatory *E. tularensis* mite populations (Tanigoshi et al. 1985). Several studies have documented the importance of pollen resources to the longevity and fecundity of predatory mites (He et al. 2022; Eini et al. 2022). Corn and sunflowers can be planted at the ends of rows to provide pollen (Whitehurst and Dietrick 2024).
- Green Lacewings (*Chrysoperla carnea*) are also key predators (Kort et al. 2020), as are Minute Pirate Bugs (*Orius spp.*) (Atakan and Pehlivan 2020). They benefit from floral resources. In the case of *Orius spp.*, they also benefit from plants such as hairy vetch (*Vicia villosa*) that have suitable substrate for them to lay their eggs (Atakan and Pehlivan 2020).
- Predatory mesostigmatid mites (*Stratiolaelaps miles*, *Hypoaspis sp*. and *Athiasiella relata*) feed on the thrips when in the soil (Colloff et al. 2013). Population of these predatory mites on the grove floor are best supported with a dense ground cover composed of perennial grasses, diverse forbs and a deep litter layer (Colloff et al. 2013).
- Assassin bugs, Dustywings, omnivorous earwigs and spiders predate upon many of the pests in citrus groves, including thrips (Walther 2024).

GRAPE PESTS:
NATURAL ENEMIES & THEIR HABITAT

LEAFHOPPERS: Two kinds of sharpshooters and three kinds of leafhoppers are major grape pests. The Glassy-winged Sharpshooter (GWSS) (*Homalodisca vitripennis*) and Blue-green Sharpshooter (BGSS) (*Graphocephala atropunctata*) feed on the xylem and are a vector for the bacterium *Xylella fastidiosa* that causes Pierce's disease, which kills vines. GWSS overwinters as an adult in evergreen plants such as citrus and avocado. The Grape Leafhopper (*Erythroneura elegantula*), the Variegated Leafhopper (*E. variabilis*) and the Virginia Creeper Leafhopper (*E. ziczac*) nymphs and adults remove the contents of leaf cells, leaving behind empty cells that appear as pale yellow spots or stippling. Reduced leaf efficiency and leaf drop can occur when leafhopper densities are extremely high. This can result in fruit sunburn and may delay fruit ripening, especially in young vines. Leafhoppers can also be a nuisance pest to workers manually harvesting the crop.

- Introduced parasitoid wasps including *Gonatocerus ashmeadi* and the native wasp *Gonatocerus morrilli* will attack GWSS eggs (UC Riverside).
- Two native wasp parasitoids, *Gonatocerus latipennis* and a *Polynema* species are known to attack BGSS (Hoddle et al. 2004).
- Sweet alyssum (*Lobularia maritima*) and annual buckwheat (*Fagopyrum esculentum*) increase the longevity and number of the progeny of *Gonatocerus ashmeadi* (Irvin and Hoddle 2007).
- Green Lacewings (Chrysopidae) (Daane et al. 1996) and predaceous mites consume nymphs of these leafhoppers (Sorensen et al. 1976).
- Hunting spiders help control leafhopper nymphs. When cover crops were present, especially late in the season, spiders were important predators (Costello and Daane 2003).
- Planting cover crops and native grasses between the vine rows helps reduce leafhopper pests by providing food for natural enemies and/or by decreasing the grape plant's ability to host leafhoppers through competition for soil nitrogen (Daane et al. 2018). Leafhoppers are attracted to vines with high vigor, so in this way, competition from cover crops can sometimes lead to lower leafhopper abundance, even in the absence of natural enemies.
- Parasitoid wasps (*Anagrus spp.*) attack Grape Leafhopper eggs during the growing season, but because this pest overwinters as an adult, the parasitoids need to use the eggs of an alternate host during this time. Wasps in California's North Coast were found to predominately utilize coyote brush (*Baccharis pilularis*) and blackberry (*Rubus sp.),* as well as roses (*Rosa spp.*), catmint (*Nepeta spp.*) and ceanothus (*Ceanothus spp.*) (Wilson et al. 2016). However, it is thought that since coyote brush and blackberry occur in large numbers throughout the region, they are the most important wasp habitat. Areas with greater natural habitat within 1/3 mile of

Lacewing larva (right) hunting leafhopper nymph
Photo: Kimberly Steinmann

the crop had higher early season *Anagrus* populations, which led to higher early season parasitism and lower late season leafhopper numbers (Wilson et al. 2016). Plants in the mint family, such as catnip, may possibly have been hosting the Sage or Ligurian Leafhoppers (*Eupteryx melissae* or *E. decemnotata*), which also occur in the area. In Canada, *Anagrus* emergent studies found roses (*Rosa spp.*), blackberry (*Rubus spp.*), apple (*Malus domestica*), lavender (*Lavendula angustifolia*) and garden sage (*Salvia officinali*) to be used by these wasps (Lowery et al. 2007).

- A hedgerow or field patches could be planted with California lilac, a great early forage for adult *Anagrus* (Long et al. 1998), perennial buckwheat (*Eriogonum spp.*) for summer forage (James et al. 2014) and coyote brush for fall forage (Wilson et al. 2016), along with other plants that support generalist predators.
- A summer cover crop composed of buckwheat (*Fagopyrum esculentum*) and sunflower (*Helianthus annus*) reduced leafhoppers and thrips and increased the numbers of predators, including spiders, and the parasitoid *Anagrus epos* (Nicholls et al. 2001).

MEALYBUGS: Vine Mealybug (*Planococcus ficus*), Grape Mealybug (*Pseudococcus maritimus*) and Obscure Mealybug (*Pseudococcus viburni*) overwinter as adults under bark on trunks and cordons. They damage grape vines and clusters by feeding and producing honeydew that serves as a substrate for black sooty mold. Mealybugs also transmit grape viruses. As honeydew-producing Homopterans, mealybugs can many times be closely tended and protected by ants.

- The parasitoids that attack mealybugs are *Anagyrus pseudococci*, *Leptomastidea abnormis*, *Acerophagus flavidulus* and *Coccidoxenoides perminutus* (Daane et al. 2012, Franco et al. 2008), which go after mealybugs on the canes and foliage.
- A beetle called the Mealybug Destroyer (*Cryptolaemus montrouzieri*) attacks mealybugs. The predator's larvae look like mealybugs, so ants don't bother them (Daane et al. 2007). Another beetle called the Little Brown Mealybug Destroyer (*Nephus sordidus*) can also provide significant predation of mealybugs and tends to be better at surviving the hot summers (Carroll 2024) and colder winters present in inland areas (Daane et al. 2012).

Mealybug Destroyer adult (top)
Mealybug Destroyer larva feeding on scale (bottom)
Photos: Flickr users Budak and Samuel

- The predaceous midge *Dicrodiplosis californica* can be a significant predator on mealybug eggs and small crawlers (Daane et al. 2012; Carroll 2024).
- Green Lacewings (*Crysoperla sp.*) and Brown Lacewings (Hemerobiidae) can also be effective predators of mealybugs in the absence of ants (Carroll 2024).

Parasitoid wasp (Ichneumon) on Apiaceae flower Photo: Dr. Guido Bohne

OMNIVOROUS LEAFROLLER & CUTWORM caterpillars can reduce vigor and growth. The Omnivorous Leafroller (*Platynota stultana*) reduces photosynthetic production of the leaf surface. The cutworm can cause significant reduction in shoot growth early after bud swell as well as sever small canes after growth has begun (Taber 2023).

- Generalist predators such as Minute Pirate Bugs (*Orius spp.*), Lacewings and spiders feed on larvae (Flint and Dreistadt 1998).
- Parasitoid wasps and tachinid flies can greatly reduce lepidopteran larvae. Parasitism rates increased when vineyards had flowering ground cover and were surrounded by habitat (Carlos et al. 2022). Flowering plant species in the Apiaceae family are known to support significant numbers of parasitoid wasps (Tooker and Hanks 2000; Wäckers and Van Rijn 2012).
- *Trichogramma*, parasitoid wasps that attack the egg stage, are commercially available (Whitehurst and Dietrick 2024).

PACIFIC SPIDER MITES (*Tetranychus pacificus*) reduce production by stippling of leaves and reducing photosynthesis. Excessive webbing can increase relative humidity at the leaf surface and cause an increase in powdery mildew problems.

- The generalist Western predatory mite (*Galendromus occidentalis*) will attack spider mites (Stavrinides et al. 2010).
- Using flowering cover crops or just conserving ground cover can increase the abundance and diversity of predatory mites in vineyards due to the increased supply of pollen that enhances their survival (Sáenz-Romo et al. 2019; Malagnini et al. 2022).

LETTUCE & CELERY PESTS:
NATURAL ENEMIES & THEIR HABITAT

Lettuce and celery share very similar pest species, hence many of the same biocontrol techniques used in lettuce can be used in celery.

APHIDS: Lettuce Aphid (*Nasonovia ribisnigri*) is the primary pest of lettuce and celery in California. The Potato Aphid (*Macrosiphum euphorbiae*), Green Peach Aphid (*Myzus persicae*) and Foxglove Aphid (*Aulocorthum solani*) are lesser pests of these crops (Smith and Chaney 2007).

- Predation of aphids in lettuce by Syrphid Fly larvae (Syrphidae) is a significant biocontrol mechanism for this pest (Brennan 2013). The main method to increase the presence of Syrphid Flies in commercial vegetable fields is intercropping sweet alyssum (*Lobularia maritima*) to attract adult Syrphid Flies into lettuce fields. These can be separate rows of alyssum between rows of vegetables (for example, every 12th row) or individual plants interspersed throughout the crop (for example, 3% of all plants in the field). When the adult female Syrphid Flies are ready to lay eggs, they will then find aphid colonies nearby in which to oviposit (Smith and Chaney 2007).
- Parasitoid wasps can also provide significant control for aphids. Sweet alyssum enhances aphid parasitism by the wasp *Diaeretiella rapae* (Patt et al. 1997). When barley is planted on the end of rows, it can be an excellent host of the cereal aphid (*Rhopalosiphum padi).* Barley acts as a reproductive reservoir (termed a "banker host") for aphid parasitoid wasps such as *Aphidius colemani* without hosting the pests of most vegetable crops (Frank 2010).
- The cereal aphid found on barley can also be important for the development of Lacewing larvae (Hogg et al. 2023).
- Green Lacewings (Chrysopidae) and Brown Lacewings (Hemerobiidae) are also predators of aphids. They are supported by sweet alyssum and lacy phacelia (*Phacelia tanacetifolia*) (Alcalá Herrera et al. 2022).
- In field trials, of three plants in the Apiaceae family–coriander (*Coriandrum sativum*), dill (*Anethum graveolens*) and fennel (*Foeniculum vulgare*)–coriander and dill had the highest richness (number of species) and abundance (number of individuals per species) of parasitoids compared to fennel, which had half as many species (De Haro et al. 2015). Lady Beetles (Coccinellidae), Big-eyed Bugs (*Geocoris spp.*), Minute Pirate Bugs (*Orius spp.*), predatory thrips (*Scolothrips and Aelothrips*), Rove Beetles (Staphylinidae) and dwarf spiders (Araneae) are predators of aphids found in lettuce insectary strips (Smith and Chaney 2007; Smith et al. 2008).
- Hedgerows composed of common yarrow (*Achillea millefolium*), coffeeberry (*Rhamnus californica*), perennial buckwheat (*Eriogonum giganteum*), California lilac (*Ceanothus griseus* and *C. 'Ray Hartman'*) and toyon (*Heteromeles arbutifolia*) are known to support Lady Beetles, Big-eyed Bugs, Minute Pirate Bugs, Lacewings and Syrphid Flies (Pisani Gareau and Shennan 2010).
- Minute Pirate Bugs supplement their diet with pollen (Patterson and Ramirez 2017). Planting corn and sunflower seeds at the ends of beds provides pollen while creating islands of diversity (Whitehurst and Dietrick 2024).
- Cover crops such as annual buckwheat (*Fagopyrum esculentum*) and crimson clover (*Trifolium incarnatum*) support high densities of beneficial insects (Clark 2012).

Syrphid fly larva feeding on aphids
Photo: Kara Jones

LEAFMINERS (*Liriomyza*) eggs are laid within lettuce leaves, and the emerging larvae make distinctive tunnels or mines in the tissue. Leafminers can also be significant pests in celery, especially during early growth.

- Parasitoid wasps *Diglyphus* are significant biocontrol agents of leafminers in lettuce (Smith 2011). Maintaining continuous growth of plants beneficial to parasitoid wasps on the field margins well in advance of transplanting crops may benefit leafminer biocontrol. There are a diverse number of these parasitoid species, and evidence points to pesticide-free areas being effective at regulating leafminers (Murphy and LaSalle 1999). In crops where the leafminer-damaged portion of the plant is harvested, such as lettuce, biological control efforts early in the season before the harvestable portion develops is critical (Liu et al. 2009). *Diglyphus* parasitoids are available commercially (Whitehurst and Dietrick 2024).

WESTERN FLOWER THRIPS (*Frankliniella occidentalis*) suck the plant sap, giving leaves a silvery appearance with scarring. They vector Impatiens Necrotic Spot Virus (INSV) to lettuce. Lettuce acquires INSV by adult thrips migrating into the lettuce field, after which the virus can be moved between lettuce plants. The virus is acquired by thrips during their first and second larval stages. Adult thrips remain infective throughout their life (Zhao and Rosa 2020). INSV-infected plants have dead spots on leaves and general yellowing and stunting. Thrips are a minor pest in celery production.

- The main biocontrol of thrips are Minute Pirate Bug predators (*Orius spp.*) which feed on thrips larvae. These predators can be enhanced with annual buckwheat (*Fagopyrum esculentum*) and cowpea (*Vigna unguiculata*) that offer sufficient floral resources as well as appropriate plant tissue for laying their eggs (Hinds and Barbercheck 2020). Sweet alyssum has been shown to be beneficial to Minute Pirate Bug populations since it provides high-quality floral resources and serves as an acceptable host where the predator can lay its eggs (Pumariño and Alomar 2012). Blooming coriander (*Coriandrum sativum*) and marigold (*Tagetes sp.*) are also alternate forage and egg-laying host plants for Minute Pirate Bugs (Zhang et al. 2021). Plants found to be non-hosts of INSV include sweet alyssum; the cereal crops oats (*Avena sativa*), barley (*Hordeum vulgare*) and rye (*Secale cereale*); coyote brush (*Baccharis pilularis*); arroyo willow (*Salix lasiolepis*); and deerweed (*Acmispon glaber*) (Smith et al. 2023).
- Since thrips go through their pupal stage in the soil, Rove Beetles (Staphylinidae) and entomopathogenic nematodes found in many healthy soil ecosystems can help control them (Lim et al. 2001; Whitehurst and Dietrick 2024).

Minute Pirate Bug eating thrips
Photo: Gary Chang

Tachinid Fly on Yarrow
Photo: John Freshney

BEET ARMY WORMS & CORN EAR WORMS: Beet army worms (BAW) (*Spodoptera exigua*) and corn ear worms (CEW) (*Helicoverpa zea*) lay eggs on young foliage. The emerging larvae feed on this foliage and then may move into lettuce heads and celery stalks as they mature. Feeding on lettuce foliage and on the later stages of celery stalk growth causes economic damage in the crop.

- Generalist predators of BAW include Assassin Bugs, Damsel Bugs and spiders. Predators of CEW are Lacewings, Minute Pirate Bugs and Damsel Bugs (Long et al. 2018).
- Wasp parasitoids of the BAW larvae in California are the wasps *Hyposoter exiguae* and *Chelonus insularis* and Tachinid Flies (Tachinidae) (Oatman and Platner 1972). *Cotesia marginiventris*, which is present in California, has also been shown to be an effective egg parasitoid of BAW eggs (Ruberson and Whitefield, 1996). *Trichogramma* wasp parasitoids attack the eggs of CEW (Long et al. 2018) and are available commercially but may require weekly releases if there is not sufficient habitat on the farm (Whitehurst and Dietrick 2024).
- Predatory ground beetles such as Carabids, Staphlinids and Wolf Spiders (Maloney et al. 2003) contribute to control of caterpillars.
- Large-bodied predators such as Lacewings and Syrphid Flies tend to disperse farther from floral resources than small-bodied Minute Pirate Bugs and small parasitoid wasps. Therefore, using both field edge and in-field habitat will enable better dispersal (Pisani Gareau and Shennan 2010).

STRAWBERRY PESTS:
NATURAL ENEMIES & THEIR HABITAT

LYGUS BUGS (*Lygus hesperus*) feed on developing, seed-like achenes of strawberries, which cause disfiguring cat-facing as berries mature and thus reduce fresh market yield.

- Predators that consume Lygus Bug include Big-eyed Bugs (*Geocoris spp.*), Damsel Bugs (*Nabis spp.*), Minute Pirate Bugs (*Orius spp.*), predatory beetles, ants and spiders (Hagler et al. 2018; Capinera 2001; Lu et al. 2021). On-farm diversification such as a hedgerow or field patches and surrounding landscape diversity increased these natural enemies and the pest control of Lygus Bugs (Lu et al. 2021).
- Alfalfa can serve as a trap crop for Lygus Bugs, especially in the spring when the adults migrate from weeds to strawberry fields. The Lygus Bug nymphs migrate to the strawberries, as do the natural enemy insects, resulting in a predator-to-lygus ratio of 5:1 (Nieto et al. 2023). Alfalfa can be planted in strips as borders and periodically cut to keep it producing both flowers and seeds, which makes it attractive to Lygus Bugs (Godfrey and Leigh 1994). Instead of cutting it all at once, cutting half the width of the strip or alternate sections periodically reduces chances for Lygus Bugs to move into the crop. A good practice is to vacuum the strips when Lygus Bug numbers are high (Whitehurst and Dietrick 2024).
- Planting non-crop vegetation such as alfalfa strips or larger hedgerows upwind of the crop can help to intercept Lygus Bugs (Mohler and Johnson 2009).
- The introduced wasp parasitoid *Peristenous relictus* attacks Lygus Bug nymphs. It has spread from its initial release locations and now occurs throughout California's primary strawberry growing regions (Nieto et al. 2020).
- Annual fleabane (*Erigeron annuus*), a native adventive plant in California (Kartesz 2015), attracts Lygus Bugs, as well as attracting the parasitoid *P. relictus* (Halloran et al. 2013). Fleabane produces volatile plant chemicals that are more attractive to Lygus Bugs than cotton, a crop they also consume. The production of these volatiles increases when fleabane is attacked by Lygus Bugs (Halloran et al. 2013). The flowers of fleabane also provide nectar resources to increase the longevity of the parasitoid wasps (Halloran et al. 2013).
- The beneficial build-up of *P. relictus* populations in California during spring and early summer is partially due to an alternate European host, the Potato Bug (*Closterotomus norvegicus*), which is found in the weedy vegetation of wild radish (*Raphanus raphanistrum*), black mustard (*Brassica nigra*), poison hemlock (*Conium*) and arrowleaf saltbrush (*Atriplex prostrata*) (Pickett et al. 2009).

LEPIDOPTERAN PESTS (caterpillars) can reduce plant vigor and growth. Fruit feeding by larvae can also cause secondary pest outbreaks of fruit flies (*Drosophila sp.*) and fungal pathogens (Lahiri et al. 2022). Lepidopteran caterpillars can cause significant loss by feeding on the crown of newly planted and older strawberry plants and can kill them.

- Green Lacewings (Chrysopidae) and Brown Lacewings (Hemerobiidae), Minute Pirate Bugs (*Orius spp.*), Lady Beetles (Coccinelidae) and spiders feed on eggs and early stages of lepidopteran larvae (Laurenz and Meyhofer 2021).

Lygus Bug on fleabane
Photo: Jimmy Smith

Jumping spider (Salticidae) feeding on caterpillar (Geometridae)
Photo: Flickr user Budak

- Parasitoid wasps and parasitoid (Tachinid) flies can greatly reduce these lepidopteran larvae (Nafziger and Fadamiro 2011; Scaramozzino et al. 2020).
- Predators and parasitoids can be supported with multiple plant resources on the farm, which will increase their food, nesting sites and shelter, enlarge the diversity of the prey available and reduce natural enemies killing one another, i.e., intraguild predation (Snyder 2019). Non-crop species can be planted in buffer hedgerows, windbreaks, beetle banks and flower strips, or can be intercropped (Gontijo 2019).

MITES: Two-spotted Spider Mite (*Tetranychus urticae*) and Lewis Spider Mite (*Eotetranychus lewisi*) reduce photosynthetic production through stippling and collapse of leaves reducing photosynthesis. High infestations can cause plant collapse and a complete lack of fruit production. These mites overwinter as adults in older vegetation and can reproduce via parthenogenesis (without mating) when warmer conditions resume.

- Specialist predatory mites such as *Phytoseiulus persimilis* prey on mites in the sub family Tetranychinae, which includes Two-spotted Spider Mites.
- Generalist predatory mites (*Neoseiulus californicus*, *Amblyseius andersoni* and *Amblyseius fallacis*) will attack all species of spider mites, as well as feed on alternative prey, pollen and even powdery mildew spores (Zemek and Prenerova 1997) when spider mites are not available (Akram et al. 2022). Some predatory mites such as *N. californicus* occur naturally, and others can be released (Aparicio et al. 2021).
- Sorghum and sudan grass borders, patches or ends of beds can host non-damaging grass mites that feed mite predators (Whitehurst and Dietrick 2024).
- Due to their small size and need for continuous cover and food resources (Albrecht et al. 2020), most predaceous mites stay near field margins, but low numbers will venture into the interior (Sikorska et al. 2019).
- The Spider Mite Destroyer, *Stethorus picipes*, which is a Lady Beetle, can contribute to mite control (Flint and Dreistadt 1998).

WESTERN FLOWER THRIPS (*Frankliniella occidentalis)* flower and fruit feeding cause flowers not to set and bronzing on berries. They can sometimes reduce crop production by causing damage to leaves, thus reducing photosynthesis.

- Predators of thrips include the predatory mites (*Neoseiulus californicus*, *Neoseiulus cucumeris* and *Amblyseius swirskii*), as well as the generalist predator Minute Pirate Bugs (*Orius spp.*) (Lahiri et al. 2022). These predators mainly feed on the larval stages of thrips due the lack of wings in larval thrips.
- Thrips larvae drop off the plant before pupation and go through their pupal stage in the soil; thus, they are also controlled by entomopathogenic nematodes found in many healthy soil ecosystems (Lim et al. 2001; Chyzik et al. 1996).
- Soil predatory mites (*Strateolaelaps scimnus*) and Rove Beetles (Staphylinidae) reduce the thrips that pupate in soil (Cloyd 2019). These are enhanced with permanent beds and decreased when plastic mulch is used (Whitehurst and Dietrick 2024).

TOMATO PESTS:
NATURAL ENEMIES & THEIR HABITAT

BEET LEAFHOPPER (BLH) (*Circulifer tenellus*) feeding damage is not significant; however, BLH is a major vector of Curly Top Virus (*Curtovirus*) in California tomatoes. This virus causes the leaves of infected plants to be purple-tinged and the fruit to turn red before maturity, eventually killing the plant. Beet leafhoppers overwinter as adults in native and non-native vegetation, then move into the tomato crop once the surrounding vegetation dries down (Davis 2023).

- The main wasp parasitoid of BLH for tomatoes is *Anagrus nigriventris*. Like other *Anagrus* species, this parasitoid requires a host that overwinters in the egg stage, not as a nymph, which is the stage in which the BLH overwinters. Catnip (*Nepeta spp.*) was found to be the plant that most *Anagrus* emerged from around North Coast vineyards (Wu 2013). The leafhopper host for *Anagrus* in the catnip during overwintering is possibly the Sage Leafhopper or the Ligurian Leafhopper (*Eupteryx melissae* or *E. decemnotata*), both of which overwinter in the egg stage within plants in the mint family (Lamiaceae), of which catnip is part. These alternate host leafhoppers may also be supported by the native black sage (*Salvia mellifera*) since the wasps were found to use garden sage (*Salvia officinali*) (Lowery et al. 2007). Coyote brush (*Baccharis pilularis*) also serves as an acceptable overwintering site for *Anagrus* hosts (Wu 2013). Both black sage and coyote brush were surveyed in a study looking at perennial plants as reservoirs for Curly Top Virus, and neither plant was found to be infected (Davis 1998).
- Wasp parasitoids attacked experimental eggs of another insect pest in BLH's same Hemiptera family up to 330 feet away from native plant hedgerows. Parasitoids were more numerous in these hedgerows, and pest insects fewer than in weedy areas (Morandin et al. 2014).
- Green Lacewings (Chrysopidae) will attack leafhopper species (Daane et al. 1996), and predaceous mites eat nymphs of leafhopper species (Sorensen et al. 1976).

APHIDS: The Potato Aphid (*Macrosiphum euphorbiae*) and Green Peach Aphid (*Myzus persicae*) are major pests of tomatoes in California (Goggin et al. 2001).

- Syrphid Fly (Syrphidae) larvae are well-known predators of aphids. Intercropping with sweet alyssum (*Lobularia maritima*) will ensure that Syrphid Fly encounter aphids present in the interior of fields (Brennan 2013).
- Parasitoid wasps such as *Diaeretiella rapae* attack aphids and will increase their parasitism when sweet alyssum is present (Patt et al. 1997). To increase populations of the wasp *Aphidius colemani*, barley is planted on the edge or in the interior of the field so the wasp can reproduce in the cereal aphids (*Rhopalosiphum padi*) (Frank 2010).
- Green Lacewings (Chrysopidae) and Brown Lacewings (Hemerobiidae), which attack aphids in crops, will also use cereal aphids to increase their numbers (Hogg et al. 2023). They benefit from the floral resources of sweet alyssum and lacy phacelia (*Phacelia tanacetifolia*) (Alcalá Herrera et al. 2022).
- Predatory Lady Beetles were more numerous and aphids were fewer in tomato fields up to 660 feet away from hedgerows. More predator species were in these hedgerows than in weedy areas (Morandin et al. 2014).

Syrphid Fly on sweet alyssum
Photo: Anne Reeves

- When at least three marigold (*Calendula officinalis*) flowers were present in greenhouses, they reduced two species of Lady Beetles (*Harmonia axyridis* and *Propylea japonica*) from eating each other, and from those of the same species cannibalizing each other (Liang et al. 2022).
- Intercropping cilantro (Coriandrum sativum) and *Sorghum* flowers in tomatoes increased natural enemies in tomatoes. Both the richness (number of natural enemy species) and the abundance of Syphrid flies (Syrphidae), parasitoid Tachind flies (Tachinidae), parasitoid wasps (Hymenoptera), beetles (Coleoptera), Dragonflies and Damsel flies (Odonata), and Lacewings and their relatives (Neuroptera) increased (Ladeia et al. 2023).
- When the predatory midge, *Aphidoletes aphidimyza,* was released at 14-day intervals into greenhouse tomatoes with high density of aphids, they significantly reduced the pests and their damage (Meadow et al. 1985). A banker plant system for *A. aphidimyza* where barley supports an alternate prey was used to control aphids in greenhouses with eggplants (Higashida et al. 2016).

LEAFMINERS are true flies (Diptera) in the genus *Liriomyza*. Damage to tomatoes is caused mainly by reduced photosynthesis of the leaves and possible interruption of vascular flow through the xylem and phloem.

- A significant biocontrol agent of leafminers are parasitoid wasps, especially in the genera *Chrysocharis* (UC ANR Statewide IPM Program 2016) and *Diglyphus* (Smith 2011). Natural enemy communities of leafminers, particularly parasitoids, are diverse within their ranges, and there is evidence that in pesticide-free areas, these can regulate leafminers (Murphy and LaSalle 1999). Maintaining continuous growth of plants beneficial to parasitoids wasps on the field margins, well in advance of the transplanting of crops into the field, may greatly benefit leafminer biocontrol.
- Predatory mirids such as *Macrolophus caliginosus*, while not as effective as parasitoid wasps, will attack tomato pests in greenhouse situations (Liu et al. 2009).
- Planting chamomile and marigold plants within the tomato crop increased the numbers of the predatory mirid bugs *M. caliginosus* (Marouf 2017).

Big-eyed Bug feeding on Whiteflies
Photo: Jack Dykinga

SWEET POTATO WHITEFLIES (SPW) (*Bemisia tabaci*, biotype B) can become a significant pest, causing reduced plant vigor in tomatoes when conditions are right. SPW can also be a significant vector of Tomato Yellow Leaf Curl (*Begomovirus*), which causes plants to be stunted and leaves to curl upward with their margins and veins turning yellow.

- Two parasitoid wasps in the genera *Encarsia* and *Eretmocerus* offer some control of SPW (Zang and Liu 2008) and can be promoted by planting flowering species before the pest infestation.
- Generalist predatory insects such Lacewings (Chrysopidae*)*, Big-eyed Bugs (*Geocoris spp.)* and Lady Beetles (Coccinelidae) can help with the biocontrol of whiteflies early in an infestation.
- The Coccinelid Beetle (*Delphastus catalinae*) is a Whitefly specialist that helps considerably to control SPW. Adults and larvae of this beetle feed on Whitefly eggs and other immature stages. *Delphastus catalinae* prefer eggs of SPW over nymphs. *Delphastus catalinae* will avoid parasitized nymphs (Hoelmer et al. 1994), and therefore is compatible with the use of parasitic wasps as biological control agents.
- Flowering plants incorporated into the field and along the field edges can greatly increase the survival and fecundity of the parasitoid wasp *Eretmocerus spp.* In trials of annual buckwheat (*Fagopyrum esculentum*) and sweet alyssum flowers, *Eretmocerus* wasps survived six times and four times longer, respectively, compared to wasps provided with only water. Buckwheat increased the parasitism rate by 72% (Araj 2019).
- In some areas, huge numbers of Whiteflies blow in on weather fronts. Having perennial habitat in place, such as hedgerows and field patches, to host predators and parasites will help in that situation (Whitehurst and Dietrick 2024).

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