Project Title: Improving pear pest management with integrated approaches

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Report Type: Final Project Report

Project Duration: 3-Year

Total Project Request for Year 1 Funding: $110,363
Total Project Request for Year 2 Funding: $114,718
Total Project Request for Year 3 Funding: $119,247

Other funding sources: Awarded

Funding Duration: 2020-2022
Amount: $323,622
Agency Name: USDA NIFA CPPM

Funding Duration: 2020-2021
Amount: $23,652
Agency Name: Washington State Commission on Pesticide Registration

Funding Duration: 2020-2023
Amount: $249,926
Agency Name: WSDA Specialty Crop Block Grant

Funding Duration: 2020-2023
Amount: $348,733
Agency Name: Western SARE

Budget 1:

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Item	2019	2020	2021
Salaries[1]	$70,200	$73,008	$75,928
Benefits[2]	$20,498	$21,318	$22,171
Wages[3]	$7,800	$8,112	$8,436
Benefits[4]	$725	$754	$785
RCA Room Rental			
Shipping			
Supplies[5]	$1,500	$1,500	$1,500
Travel			
Plot Fees[6]	$9,640	$10,026	$10,427
Miscellaneous			
Total	$110,363	$114,718	$119,247

Footnotes: [1]Research Assistant Professor, 12 months (year 1,2,3), [2]Benefits for Research Ass. Prof. 29.2%. [3]Wages for time-slip help, 1.0 FTE, summer. [4]Benefits for time-slip 9.3%. [5]Supplies – office and lab supplies, electronics, statistical consulting. [6] 3 years x $2,500/year (total acreage maintenance) + $2,100/acre (fees) on 3.4 acres

Objectives:

1. Determine lethal and sublethal effects of common insecticides to psylla natural enemies.
2. Compare particle film effects on pear psylla and natural enemies.
3. Evaluate potential for augmentative releases of earwigs for psylla control.
4. Examine novel strategies for psylla control including soil/root systemic insecticide applications, insecticide-infused netting, and reflective ground covers.
5. Determine baseline toxicities for new insecticides on two stages of pear psylla. Evaluate efficacy of other materials against pear pests *ad hoc*.

Significant Findings and Accomplishments (2021-2022):

- Numerous organic, selective conventional, and broad-spectrum conventional insecticides were examined for direct mortality and sublethal effects on natural enemies.
    - Altacor, AzaDirect, Celite, Centaur, Cinnerate, Esteem, Surround, Ultor had no mortal effects on natural enemies.
    - Actara, Admire, AgriMek, Assail, Bexar, Delegate, and Rimon caused moderate to high mortality in most, but not all assays.
    - Malathion caused high (near 100%) predator mortality in all assays.
    - Bexar consistently reduced activity (distance traveled) in individuals that survived sprays. IGRs and AgriMek affected activity in some assays, but results were not consistent. *Not all materials were tested for sublethal effects.
- Surround, Celite, Microna, and Cocoon did not significantly reduce survival of pear psylla young nymphs when sprayed over young nymphs (however, all did in 2020). In 2020, Surround and Celite provided 95-100% reductions of psylla oviposition, relative to checks, which was more effective than Microna (60% reductions).
- Earwig releases in conventional orchards using broad spectrum insecticides did not establish; however, in selective (soft) conventional orchards, earwigs increased significantly following releases. This may have occurred regardless of releases, as control sites (no releases) within selective conventional orchards experienced similar increases in earwigs.
- Mylar and Extenday suppressed pear psylla population by approximately 50% in organic commercial orchards. Extenday's effects were longer lived than mylar, likely due to durability and placement in the center of drive rows where it is not shaded. Both appeared to increase pear yield according to the grower (not officially measured).
- Bexar LC_{50}s for psylla nymphs and adults were determined for five colonies established in 2020. The average LC_{50}s of all colonizes were 129 mg (AI) /liter (H_2O) for young nymphs and 102 mg (AI) /liter (H_2O) for adults. The field rate (27 fl oz/ acre) at 100 gpa equals 339 mg (AI) /liter (H_2O), for comparison.
- <u>**Funding Leveraged Using Data from this Project**</u>:
    - USDA NIFA Crop Protection and Pest Management Grant, "Expanding the Pear IPM Toolbox", 2020-2022: **$323,622**.
    - WA State Commission on Pesticide Registration, "Pear psylla baseline toxicity to Bexar (tolfenpyrad) and non-target effects", 2020-2021: **$23,652**
    - WSDA Specialty Crop Block Grant, "Developing a phenology-based management program for pear psylla", 2020-2023: **$249,926**
    - Western SARE, "Wigging out, then wigging in: Earwig capture and augmentation for biocontrol in pears and apples", 2020-2023: **$348,733**

Obj. 1. Determine lethal and sublethal effects of common insecticides to psylla natural enemies.

Methods:

Lady beetles and earwigs were collected from unsprayed Bartlett and Anjou trees at the WSU Tree Fruit Research and Extension Center near Wenatchee, WA from June 2021-September 2021. Field collected natural enemies were exposed to pear leaves with pesticide residues individually at the maximum allowable field concentrations or a control treated with pure water in clean 1 oz solo cups (Fig 1). For each treatment and predator, there were at least 6 replications each with 5 individuals per rep (30 individual/treatment/experiment). A damp cotton wick was added to cups with survivors after 24 hours of exposure to prevent desiccation. Pesticide exposures consisted of either 1) direct spray, 2) high load residues on soaked and dried filter paper, or 3) a pear leaf dipped into the pesticide mixture and cut into five ≤1 ¼-inch diameter leaf discs. Leaf disk methods were also used to test residues at increasing time intervals following treatment. Mortality was documented in direct spray trials after 48 hours, and in residue exposures every 24 hours until hour 144. Insect species that exhibited mortality above controls from direct exposure at 0 hours of pesticide aging were subsequently exposed to aged residues to determine susceptibility to insecticides. If no mortality occurred from a material following direct contact, aged residues were not tested.

Fig 1. Predator bioassay arena. Dead earwig, dipped pear leaf, and cotton wick are pictured.

Sublethal effects (EthoVision): For most experiments, surviving individuals were tested for sublethal effects on activity using EthoVision. The primary response variable examined thus far is *distance traveled*, as this provided data with the least variability. Analysis and further examination are still being conducted.

Results:

Mortality: Mortality of earwigs and lady beetles from direct exposure is presented in Fig. 2, and fresh residues in Fig. 3. Due to the large number of treatments, exposure types, and residues for two insects, not all data are ready for presentation in this report. We are currently creating a webpage to go on the WSU Tree Fruit Pear IPM website for the comprehensive dataset.

Sublethal Effects: Insect growth regulators (IGRs) (Ultor, Esteem, Centaur, and Rimon) and Altacor had consistently negligible effects on mobility of earwigs and lady beetles. Actara, Assail, and Bexar had mixed outcomes, but each significantly reduced mobility in at least one assay. This suggests that IGRs are unlike to affect behavior or mobility of surviving insects, while mid-spectrum contact materials may result in impair mobility.

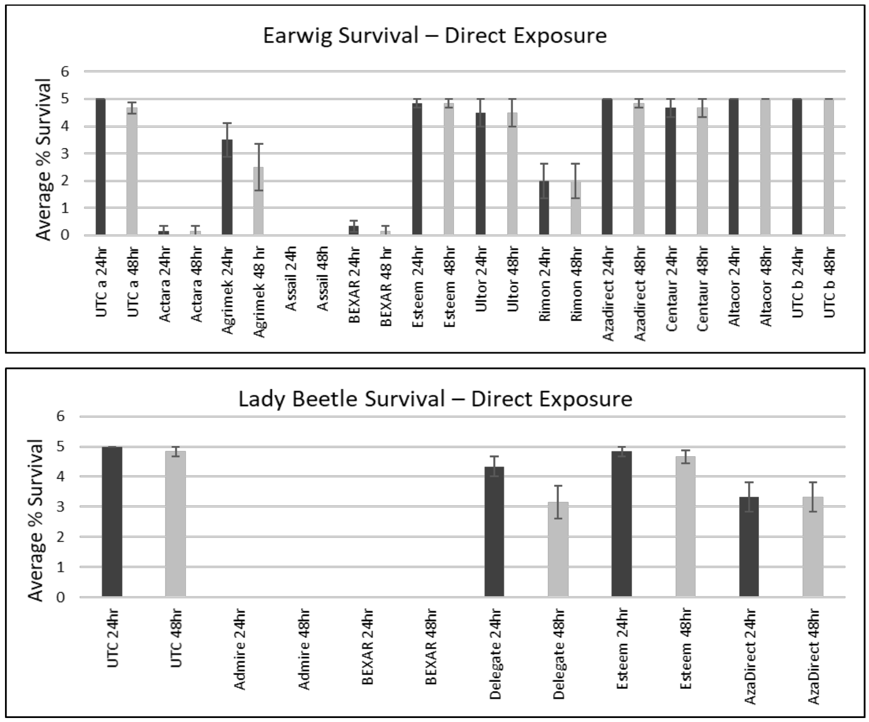

Fig. 2. Non-target effects. Survival of earwigs (top) and lady beetles (bottom) following exposure to insecticides as direct sprays, evaluated 24 and 48 hours after exposure.

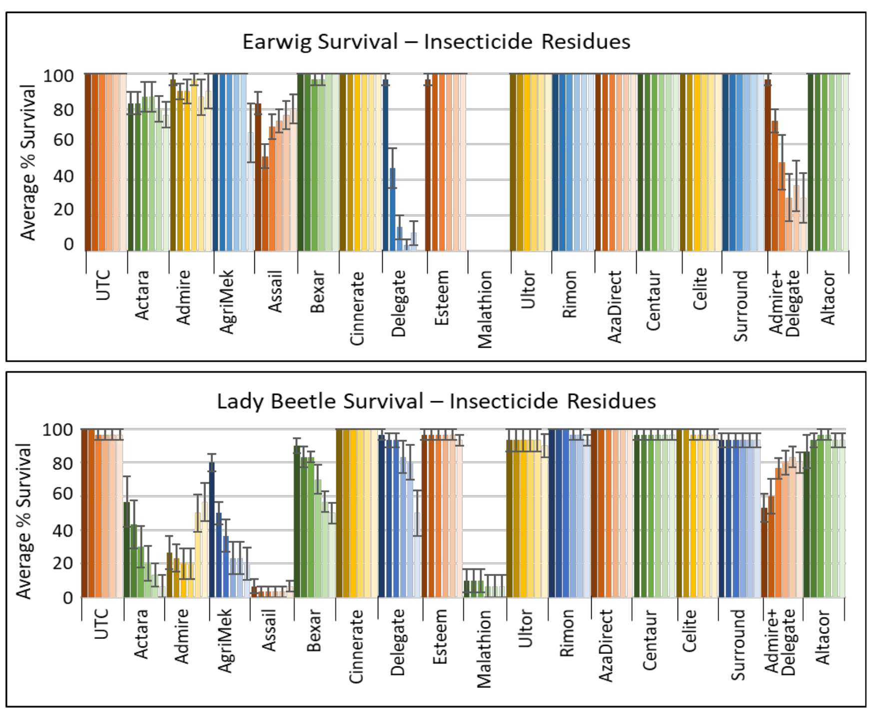

Fig. 3. Non-target effects. Survival of earwigs (top) and lady beetles (bottom) following Exposure to insecticides residues. Bars above a treatment moving left to right depict evaluations at increasing times after treatment.

<u>Obj 2</u>. Compare effects of particle films on pear psylla and natural enemies.

Methods:
Most of the work on this objective was completed in years 1 and 2. A final experiment was performed in 2021 to gain a second test on the effect of particles films on psylla nymphs (particle films sprayed over psylla as nymph instars 1-2). This experiment was conducted in May 2021 in an untreated pear orchard at the WSU TFREC. Leaves with at least 20 psylla eggs were found and tagged with a treatment and rep ID. Surrounding leaves were removed and tanglefoot was placed around the petiole to prevent nymphs from leaving or being attacked by predators. Each leaf was sprayed with one of each particle film (Surround, Celite, Microna, or Cocoon), at a concentration equivalent to 50 lb/ac. At 100 GPA (i.e., 60 g/L). Leaved remained attached to tree, and after 14 days, leaves were removed and brought back to the lab so surviving nymphs could be counted under a stereoscope.

Results:
Surround, Celite, Microna, and Cocoon did not significantly reduced survival of pear psylla young nymphs compared with the untreated check, but variability in nymph numbers per leaf was very high (Fig. 4). Surround and Celite resulted in the lowest averages, followed by Microna and Cocoon, respectively.

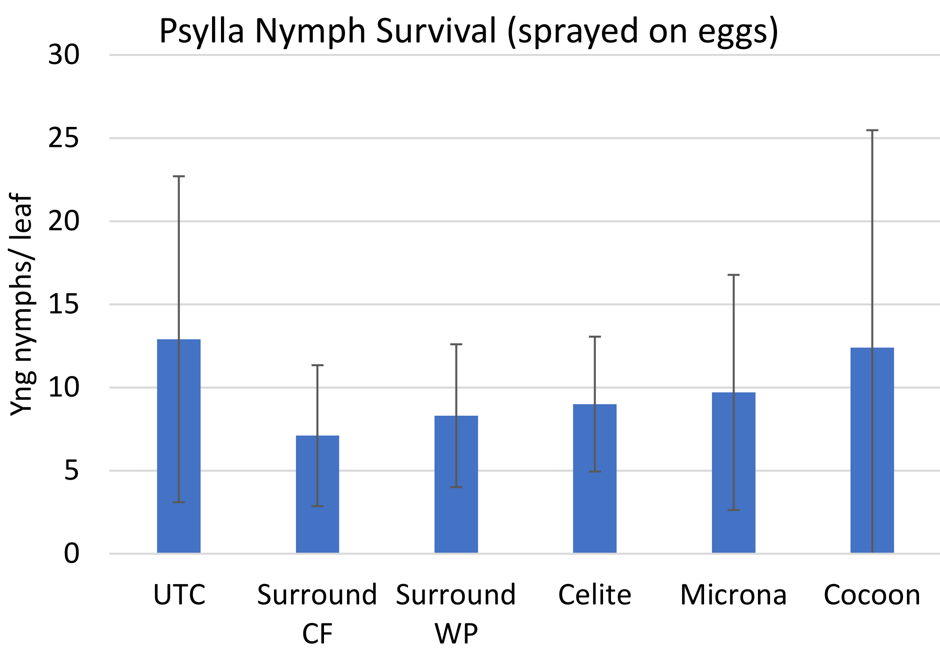

Fig 4. Survival of psylla nymphs 11 day after being sprayed by each particle film (eggs at time of spray). Treatments were not significantly different according to ANOVA.

<u>Obj. 3</u>. Evaluate potential for augmentative releases of earwigs for psylla control.

New field sites were established for earwig release experiments in 2020 to prevent carryover from the previous year affecting 2020 plots. 2019 field sites were monitored in 2020, however low recaptures in all but one site caused us to attempt a new set of methods to measure inoculation success and dispersal in smaller plots with more replications.

Methods:
From July to August 2021, earwigs were monitored in cardboard shelters placed in 4 "release" and 4 "control" plots in each of three pear orchards with low or no earwigs previously. Orchards were

located in Cashmere, Peshastin, and Rock Island. All treatment plots consisted of five adjacent pear trees, each receiving one corrugated cardboard shelter on its trunk just below the first major limb. Variable numbers of earwigs were released in release plots from July to August (143 per tree at Rock Island, 155 at Peshastin, 275 at Cashmere) with the goal of boosting earwig counts to over five per shelter per visit. All plots were over 30 m (98 ft) distant from each other, and shelters were placed in intermediate trees between each release and control plots to assess movement of earwigs.

Results:

No earwigs were found in the conventionally managed orchards in 2021 until August, during and after which a maximum of only 0.22 earwigs per shelter were found per day (Fig. 5). There was no relationship between numbers of earwigs found and release vs. control plot type. In contrast, at the WSU Rock Island research orchard (Sunrise) earwigs were first found in June and reached a maximum of about 25 per shelter in mid-July (this site had 1-2 earwigs per shelter prior to this experiment) (Fig. 5). High numbers of earwigs were found at Sunrise in both the control and release plots. Because of this, and the lack of earwigs at the two conventional sites, we could not assess whether the presence vs. absence of earwigs within a site affected pear psylla populations. The increase in earwigs from a maximum of 1–2 per shelter in 2018 and 2019, to ca. 10 per shelter in 2020 (when earwigs were released for this project), to ca. 30 per shelter in 2021 suggests that earwigs can persist and grow populations when spray programs are compatible with them. In contrast, the two conventional sites used many broad-spectrum sprays including Bexar, Rimon, and neonicotinoids known to harm earwigs. Further research should focus on orchards transitioning to soft programs (conventional or organic), and determine if earwig releases are necessary, or if populations are likely to increase naturally when less disruptive spray programs are employed.

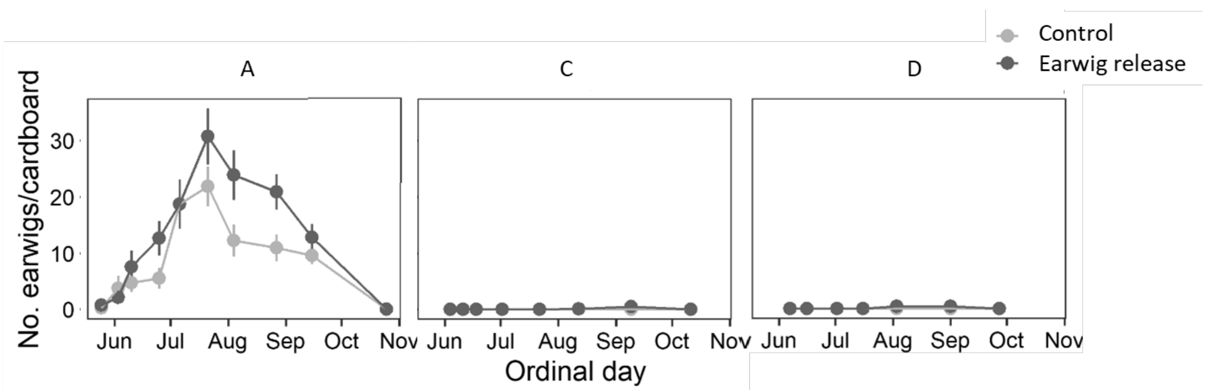

Fig. 5. Year 2021 mean earwigs per shelter (with standard error) at each of three orchards (A = Sunrise, C = Cashmere, D = Peshastin) in N = 4 release and control plots per orchard, with each plot consisting of five trees monitored with cardboard shelters. Earwig releases were conducted in 2020.

<u>Obj. 4</u>. Examine novel strategies for psylla control including soil/root systemic insecticide applications, insecticide-infused netting, and reflective ground covers.

Methods:

In 2020, we monitored pear psylla at five commercial pear orchards trialing mylar and Extenday. Each site had each of three treatments, mylar, Extenday and UTC, used in addition to the growers' standard conventional program. Because the conventional programs controlled psylla through the early season, when reflective mulches are supposed to be most effective, there was little room for improvement. In 2021, we redesigned to the experiment to be tested in organic orchard systems, where early season control is more difficult. The experiment was conducted in an organic pear orchard in Dryden, WA with very high psylla pressure. Four replicated plots of each treatment (Extenday, mylar, and control) were established in a randomized complete block design. Each treatment plot was about 0.25 acre (0.1 ha), with five drive rows, 25 m (82 ft) long. Cultivars at the site were a mix of Anjou, Bartlett, and Bosc. Mylar was placed in weed strips underneath trees, while Extenday covered the grassy drive rows. Groundcovers were installed on 17 March and removed 8 August. Sampling of insects was conducted each either weekly or biweekly throughout the season. At the end of the season, fruit were evaluated for horticultural defects and size using an AWETA fruit packing line and cup scanning grader (particularly to evaluate sunburn and blush that may occur from increased light intensity).

Results:

Extenday suppressed pear psylla adults by ca. 50% during spring and summer, and mylar suppressed pear psylla adults to a similar extent in spring only (Table 1). After ground covers were removed there were no effects on pear psylla eggs, nymphs, or spider mites, except there were more nymphs found in Extenday plots during fall. We found no evidence that pear weight, length, width, or sunburn was affected by reflective groundcovers (Table 2). The participating grower subjectively observed more fruit per tree in Extenday plots, and mylar plots to a lesser extent, so is planning to increase the scale of their trials in 2022 outside of this research project.

Table 1. Pest monitoring data from 2021 reflective groundcover trial: mean and SEM (N = 4 plots per treatment) of pear psylla life stages (adults per tray, eggs per bud in spring, eggs per leaf in summer and fall, nymphs per leaf) and pest mites (*Tetranychus* spp per leaf) by treatment across four sampling time ranges (precount, 2 March; spring, 18 March to 14 May; summer, 21 May to 6 Aug; fall, 18 August to 18 October). Values are mean seasonal averages within a time range. Mylar and Extenday were present during spring and summer. Different letters within a column for a life stage indicate significant differences (Tukey test, α = 0.05).

		Precount		Spring		Summer		Fall	
Insect	Treatment	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
Psylla Adult	Control	10.5	± 0.91	**0.90 a**	± 0.04	**0.24 a**	± 0.06	1.81	± 0.31
	Mylar	11.2	± 0.47	**0.44 b**	± 0.03	**0.30 a**	± 0.02	1.83	± 0.22
	Extenday	11.3	± 1.5	**0.39 b**	± 0.04	**0.10 b**	± 0.02	1.69	± 0.27
Psylla Egg	Control			2.62	± 0.84	1.23	± 0.40	4.65	± 2.6
	Mylar			0.97	± 0.23	1.18	± 0.46	4.26	± 1.7
	Extenday			1.28	± 0.15	0.31	± 0.10	8.54	± 3.9
Psylla Nymph	Control			0.46	± 0.16	2.71	± 0.55	**4.69 a**	± 2.0
	Mylar			0.35	± 0.25	3.73	± 1.3	**5.41 a**	± 2.0
	Extenday			0.12	± 0.05	2.02	± 0.89	**12.0 b**	± 2.6
Spider mites	Control			0	n/a	6.74	± 2.3	12.1	± 6.3
	Mylar			0	n/a	7.66	± 2.5	3.90	± 1.8
	Extenday			0	n/a	4.24	± 1.2	15.0	± 7.3

Table 2. Mean and SEM of weight, length, width, and percentage sunburn on 80 Bartlett pears from each of N = 5 plots per treatment collected on 18 Aug for the 2021 reflective groundcover experiment.

	Weight (g)		Length (mm)		Width (mm)		Sunburn (% area)	
Treatment	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
Control	185.5	± 3.7	105.9	± 0.8	69.6	± 0.8	6.6	± 1.3
Mylar	188.7	± 5.1	104.7	± 0.8	70.3	± 0.7	8.8	± 0.8
Extenday	186.0	± 4.7	103.3	± 1.5	70.3	± 0.6	7.0	± 0.7

Objective 5. Determine baseline toxicities for new insecticides on two stages of pear psylla. Evaluate efficacy of other materials against pear pests ad hoc.

Methods:
Baseline toxicity assays for Bexar on psylla adults and nymphs were conducted in the spring of 2020. Five populations from Wenatchee, Yakima, and Okanogan, WA, and Hood River and Medford, OR were used to start colonies in a greenhouse at the WSU TFREC. Colonies were kept in mesh cages (two per region) with potted Anjou trees. For each population we conducted lethal concentration probit bioassays to determine LC10, 50 and 90 values for summerform adults and first-second instar nymphs. Adults were tested using the standard slide dip method in which adult psylla are adhered via their wings to double-sided tape on a microscope slide, then dipped into a solution of pesticide. Nymph assays were conducted by collecting leaves from psylla colony pear trees with at least three young nymphs, then leaves were dipping in a pesticide solution. Six concentrations of Bexar were used for treatments along with an untreated check. Mortality was rated at 24 hours after exposure, and not later due to rapid degradation of checks. The resulting LC values are shown below in Table 1.

Results.
Probit results for pear psylla nymphs and adults are shown in Table 2. Numbers of insects (n; sb = treated subjects, ctrl = untreated controls) are given with LC_{50} and 95% confidence intervals (CI) along with X^2 and slopes from R probit analysis. Hood River adults were more susceptible to Bexar than Wenatchee and Medford; Omak and Wapato were intermediate. Overall, the average LC50 value for nymphs was 109 mg (AI) /liter (H_2O), and for adults was 74.1 mg (AI) /liter (H_2O). When comparing regions, there was no difference in susceptibility for nymphs. These data can be used in the future as comparison if resistances in expected. We will publish the raw dataset in addition to summarized results to aid future comparisons.

Table 1. Results of LC50 analysis for Bexar used on C. pyricola nymphs and adults from populations in pear growing regions of Oregon and Washington.

Colony[a]	**n (treated, ctrl)**	**LC_{50} (95% CI)**[b]	**Slope (SE)**	**X^2 (*P* value)**	**Heterogeneity factor**
Nymphs					
HR	559, 86	99.9 (64.6 – 166.0)a	1.2 (0.09)	124*	3.1
MED	633, 115	67.0(40.5 – 123.9)a	1.1 (0.08)	167*	4.1
OMA	520, 131	135 .5(68.4 – 407.0)a	0.9 (0.09)	168*	4.2
WAP	877, 147	73.0 (50.6 – 111.7)a	1.2 (0.08)	167*	3.6
WEN	1173, 150	174 (98.0 – 425.1)a	0.9 (0.06)	292*	6.4
Adults					
HR	192, 33	24.6 (9.6-50.5)b	1.0 (0.13)	75*	2.2
MED	411, 64	101.5 (54.4-207.0)a	0.71 (0.08)	146*	2.1
OMA	216, 36	49.0 (26.1 -86.9)ab	0.99 (0.13)	51*	1.5
WAP	213, 35	56.5 (36.7 – 85.9)ab	1.1 (0.13)	42	
WEN	216, 36	138.9 (79.0 – 273.3)a	0.99 (0.13)	50*	1.5

[a]HR= Hood River, OR; MED = Medford, OR; OMA = Omak, WA; WAP = Wapato, WA; WEN = Wenatchee, WA
[b]Heterogeneity factor used in calculating 95% CI when $P < 0.05$ for X^2 goodness-of-fit, Locations followed by the same letter have overlapping 95% CI
* $P < 0.05$

Executive Summary

Title: Improving pear pest management with integrated approaches

Keywords: Pear Psylla, earwigs, particle films, reflective mulch, Bexar

Abstract. The goal of this project was to test multiple strategies and contributing factors to improve IPM programs for pear pests, mainly pear psylla. This project examined strategies such as reflective mulches, particle films, earwig releases for biological control, chemical insecticide efficacy, non-target effects of insecticides on natural enemies, and established baseline toxicities of a new insecticide, Bexar (tolfenpyrad) against pear psylla adults and nymphs, to aid resistance testing in the future. Many of the objectives provided preliminary information that allowed us to leverage additional funding from state, regional, and federal agencies to conduct more thorough investigations.

Summary. *Objective 1* examined non-target effects of pesticides on natural enemies. Findings demonstrated that many insecticides used in pears fall in between "selective" and "broad-spectrum"; i.e., causing mortality of 40-60% of individuals tested (natural enemies or psylla), or have high mortality on one species and little mortality on another. These "mid-spectrum" chemicals make up much of our conventional programs, such as imidacloprid, thiamethoxam, acetamiprid, novaluron, abamectin, spinetoram, and tolfenpyrad. However, some materials proved to be consistently selective or broad-spectrum. Selective chemistries included horticultural oils, pyriproxyfen, spirotetramat, chlorantraniliprole, azadirachtin, cinnamon oil, kaolin, and diatomaceous earth; broad spectrums included malathion. It would be useful to examine more product mixes in future tests. Mixing "mid-spectrum" chemistries is common, and this is likely to create a much more toxic outcome for natural enemies.

Objective 2 compared different particle films against pear psylla, with the primary focus on determining the relative efficacy of products formulated for psylla control (Surround [kaolin] and Celite [diatomaceous earth]) vs other particle films intended for non-insecticidal uses (Microna [calcium carbonate] and Cocoon [kaolin]). Overall, Surround and Celite provided the best and most consistent control of pear psylla, primarily by repelling adults from colonizing and ovipositing on pear trees. All products had variable abilities suppress nymph development, though often significant. Overall, Surround and Celite were the most reliable products, and sprays timings should precede adult colonization and egg lay.

Objective 3 examined the potential to release earwigs to reestablish populations in locations with low densities, providing control of pear psylla. Our results demonstrate that aggressive conventional programs prevented earwigs from establishing, so there is little merit in releasing earwigs into conventional orchards unless they are transitioning to soft or organic. In situations where soft or organic programs are being used, earwigs seem to re-establish naturally, and faster than expected, but more work is needed in transitional orchards to confirm. Earwig trapping and releases can be performed with little effort, and other works suggest that releases can increase biocontrol in tree fruit; so, this tactic may still have merit in organic, IPM, or transitional orchards.

Objective 4 trialed novel strategies to control pear psylla including reflective ground covers (Mylar and Extenday), soil applied systemic insecticides, and insecticidal netting. Insecticidal netting was ineffective at controlling psylla, likely due to the chemistry infused, the pyrethroid deltamethrin, which is not an effective mode of action against psylla. Reflective ground covers used in an organic program provided and addition 50% reduction pear psylla. Reflective ground covers did not provide added control to conventional programs, because broad-spectrum sprays provide nearly complete control of psylla at this point in the season. Further studies should examine the overall economic cost and benefits to determine if reflective ground covers are cost effective. The primary grower trialing these products claimed that he would continue to use them due to increased yields and added control of psylla. The soil-applied insecticide, Platinum (thiamethoxam), resulted in about an 80% reduction in psylla nymph survival. Movento (spirotetramat) did not reduce pear psylla survival. Although the soil drench method was effective for Platinum, the material is not currently registered for use in pears, and in the current regulatory climate around thiamethoxam it is not likely to be. Registered materials for soil drenches in pears, like Admire Pro, could be tested; however, Admire Pro is also under regulatory pressure for pollinator and other environmental concerns.

Objective 5 established Bexar LC_{50}s for pear psylla adults and nymphs from five regional populations of pear psylla, including Washington, Oregon, and New York. LC_{50}s combined across regions were 109 mg (AI) /liter (H_2O) for young nymphs and 102 mg (AI) /liter (H_2O) for adults. The field rate (27 fl oz/ acre) at 100 gpa equals 339 mg (AI) /liter (H_2O), for comparison. Other insecticides were tested in various independent bioassays and field trials.

Most insecticide trials have been published in the open-access journal Arthropod Management Tests (some are still in review or in prep). We are currently preparing a webpage for the Tree Fruit Extension Pear IPM website that will house all insecticide trials and other trial results from this project.