

Project Title: Developing a Leafhopper Degree-day Spray Program for Cherry IPM

Report Type: Final Project Report

Primary PI (since fall 2024): Dr. Tobin Northfield

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Cooperators: Teah Smith, Garrett Bishop, Jenna Voelker, Dr. Katlyn Catron, Dr. Rodney Cooper, Dr. Scott Harper, Dr. Adrian Marshall, Dr. David Crowder

Project Duration: 3 Year

Total Project Request for Year 1 Funding: \$ 77,930

Total Project Request for Year 2 Funding: \$ 80,918

Total Project Request for Year 3 Funding: \$ 84,025

Total Request: \$242,873

Other related/associated funding sources: Awarded

Funding Duration: 2020–2023

Amount: \$36,000

Agency Name: Corteva Agriscience, Gowan Co, Brandt Co., Nichino America, Kemin Industries, GroPro

Notes: Funds from chemical industry contribute to salaries and research in Obj. 3.

Other related/associated funding sources: Awarded

Funding Duration: 2023-2025

Amount: \$249,813

Agency Name: WSDA Specialty Crop Block Grant

Notes: Project “Leafhopper phenology model development and habitat assessment to improve cherry X-disease management” was awarded to PI Orpet and co-PI Northfield to support leafhopper sampling and expand monitoring to habitat bordering orchards.

Other related/associated funding sources: Awarded

Funding Duration: 2022-2025

Amount: \$324,588

Agency Name: USDA NIFA, Crop Protection and Pest Management

Notes: Project “Integrating vector and pathogen phenology to optimize X-disease management” was awarded to PI Northfield and co-PIs Adams, Nottingham, and Galimba to sample leafhoppers and X-disease infected trees for two years.

Budget 1

Primary PI: Tobin Northfield

Organization Name: WSU TFREC

Contract Administrator: Kevin Rimes

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Station Manager/Supervisor: Lee Kalcsits

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Item	2022	2023	2024
Salaries	\$47,727.00	\$49,636.00	\$51,621.00
Benefits	\$17,498.00	\$18,198.00	\$18,926.00
Wages	\$5,760.00	\$5,990.00	\$6,230.00
Benefits	\$551.00	\$573.00	\$596.00
RCA Room Rental	\$0.00	\$0.00	\$0.00
Shipping	\$0.00	\$0.00	\$0.00
Supplies	\$0.00	\$0.00	\$0.00
Travel	\$0.00	\$0.00	\$0.00
Plot Fees	\$0.00	\$0.00	\$0.00
Miscellaneous	\$0.00	\$0.00	\$0.00
Total	\$71,536.00	\$74,397.00	\$77,373.00

Footnotes:

¹Nottingham Salary: \$7,612 x 12 mo x 2% FTE = \$1,827 for year 1 x 1.04 each additional year. Benefits at 29.9%

²Postdoc Salary: \$4,250 x 12 mo x 90% FTE = \$45,900 for year 1 x 1.04 each additional year. Benefits at 36.9%.

³Non-student temporary employee: \$15/hr x 16 hrs/wk x 24 wks = \$5,760 for year 1 x 1.04 each additional year. Benefits at 9.6%

⁴Funded with industry gifts and leveraged matching funds.

Budget 2**Co PI 4:** Christopher Adams**Organization Name:** OSU - Agricultural Research Foundation**Contract Administrator:** Sonia Voigt**Telephone:** 541-386-2030**Contract administrator email address:** sonia.voigt@oregonstate.edu**Station Manager/Supervisor:** Brian Pearson**Station manager/supervisor email address:** brian.pearson@oregonstate.edu

Item	2022	2023	2024
Salaries	\$0.00	\$0.00	\$0.00
Benefits	\$0.00	\$0.00	\$0.00
Wages	\$5,760.00	\$5,875.00	\$5,993.00
Benefits	\$634.00	\$646.00	\$659.00
RCA Room Rental	\$0.00	\$0.00	\$0.00
Shipping	\$0.00	\$0.00	\$0.00
Supplies	\$0.00	\$0.00	\$0.00
Travel	\$0.00	\$0.00	\$0.00
Plot Fees	\$0.00	\$0.00	\$0.00
Miscellaneous	\$0.00	\$0.00	\$0.00
Total	\$6,394.00	\$6,521.00	\$6,652.00

Footnotes:

¹Non-student temporary employee: \$15/hr x 16 hrs/wk x 24 wks = \$5,760 for year 1 x 1.04 each additional year. Benefits at 11%.

²Funded with industry gifts and leveraged matching funds.

Objectives

1. Collect model development and validation data: scout selected WA and OR orchards containing high populations of leafhoppers twice per week while compiling weather data.

Deviations: Scouting occurred weekly in 2022, 2023, and 2024. This project was leveraged to obtain a federal grant to continue collecting through 2025.

2. Modeling phenology curves: Use leafhopper abundance data to parameterize and validate the model.

Deviations: The objective is completed, but we are using one more year, funded by federal funding leveraged by this project to fit the model to improve model coverage across multiple years.

3. Insecticide trials: Screen conventional and organic insecticides for efficacy against leafhoppers and partner with growers to test spray timings.

Deviations: Some new laboratory tests were conducted. In addition, we conducted simulation models to evaluate different timings on orchard longevity. Models suggested orchards survive the longest when insecticides are timed at early adult emergence, rather than during the nymphal stage as previously hypothesized. The degree day model can supplement trapping to inform this timing.

Significant Findings

- Relative abundance of leafhoppers of concern in Washington and Oregon orchards have been defined. From 2022–2023, a total of 28,661 adult leafhoppers were counted on sticky cards and 26,188 from vacuum samples. Most of the leafhoppers were species we can assume are innocuous to tree fruit production (64% and 77% of total leafhopper catch from sticky card and vacuum sampling, respectively). Among the three main assumed potential vectors of X-disease, the most common were *Colladonus reductus* (20%, 6%) and *Euscelidius variegatus* (14%, 16%). Oregon sites tended to have relatively more *E. variegatus*. The third species, *Colladonus geminatus*, was least common (1.3%, 0.4%).
- *Colladonus montanus reductus* adults have three seasonal peaks in orchards. Adults first appear as early as May, peaking in June–July. A summer peak usually occurs in August. A final peak occurs in fall, with adults persisting through November. The size of the peaks can vary greatly between peaks, locations, and years.
- Visual inspection, dissection, molecular diagnosis, and literature review conducted among the laboratories of co-PIs and collaborators indicated *E. variegatus* adults vary greatly in pigmentation. This results in a gradient of light and dark forms. Due to earlier confusion, adults of this species were previously undercounted on this project in Washington. They were re-counted for the current report.

Methods

Site selection. In 2022, 10 Washington and three Oregon orchards were selected for vacuum and sticky card sampling (Table 1) in consultation with industry cooperators Bishop, Voelker, and Smith. Orchards were chosen where large numbers of leafhoppers were expected. The orchards were either apricot, cherry, nectarine, apple, or pear. In 2023, the same sites were used, except Richland 1 was replaced with Richland 2 because few leafhoppers were found at Richland 1 in 2022. In 2024, two sites were cut to improve sampling route efficiency and reliability of weekly coverage (Richland 2 and Prosser 1).

Leafhopper monitoring. In 2022–2024, leafhoppers were monitored from May through October using sticky card and vacuum methods. Variable methods were used in 2022 between Washington and Oregon, but methods were standardized among locations starting in 2023.

For sticky cards, in 2022, two yellow cards were collected and replaced from the lowest-height tree limbs for Washington sites, and one sticky card was collected and replaced from a wooden post between two trees for Oregon sites. In 2023, all sites used two sticky cards placed on low limbs. In 2024, three sticky cards were placed per orchard, on wooden posts. The number of *C. reductus* adults, *C. geminatus* adults, *E. variegatus* adults, and other leafhopper adults on each card was recorded.

For vacuum samples, in 2022, Washington site sampling was conducted in a standardized area based on nine 0.81-m (32-inch) diameter circular areas per site whereas Oregon sites standardized sampling based on walking 56–82 m (180–270 ft). In 2023 and 2024, sampling was standardized to nine 0.81 m (32-inch) diameter circular areas per site. A 5-gallon paint strainer bag, held on the vacuum tube with rubber bands, collected the insects and prevented them from being sucked into the motor. After vacuuming, the contents of the paint strainer bag were emptied into a zip-top bag. Zip-top bags were returned to the lab and frozen for later quantification of leafhoppers.

Temperature monitoring. At each site temperature sensors, METER Group ZL6 Advanced Cloud Data Loggers with ECT/RT temperature sensors were installed to record air temperature every 15 minutes. However, temperature data from loggers was found to be unreliable will not be used. Rather, we have used the nearest Agweathernet and AgriMet weather stations, using hourly average temperature.

Table 1. Site names, fruit crops, and years sampled for leafhoppers in 2022–2024.

State	Site	Fruit Crop	Years sampled
Washington	Peshastin	Pear	2022, 2023, 2024
	Wenatchee	Pear	2022, 2023, 2024
	Rock Island 1	Apple	2022, 2023, 2024
	Rock Island 2	Apple	2022, 2023, 2024
	Royal City 1	Cherry	2022, 2023, 2024
	Wapato	Apricot	2022, 2023, 2024
	Zillah	Cherry	2022, 2023, 2024
	Richland 1	Nectarine	2022
	Richland 2	Apple	2023
	Prosser 1	Cherry	2022, 2023
	Prosser 2	Cherry	2022, 2023, 2024
Oregon	Hood River	Cherry	2022, 2023, 2024
	Mosier 1	Cherry	2022, 2023, 2024
	Mosier 2	Cherry	2022, 2023, 2024

Model development. A Johnson SB model (Jones and Wiman 2012) was fit to leafhopper counts on traps in 2022 through 2024. Sites with particularly low counts (never more than one leafhopper per trap per day) were removed before analyzing. The model measures degree day accumulation, measured hourly $[(\text{temperature} - \text{base})/24]$, where “base” is the base temperature. Initially we used the base temperature of 58°F, which is the minimum temperature for development of beet leafhopper. However, after evaluating other base temperatures, a minimum value of 45 °F was found to fit the data better. We assumed a negative binomial error distribution to account for the nature of the count data.

Simulation model. To better understand ideal spray timings, we developed and evaluated a simulation model inspired by *C. reductus* biology. Given the month-long latency period in *C. reductus*, we assumed that vectors acquire the phytoplasma as nymphs and transmit as adults. Thus, we hypothesized that it would be most effective to target nymphs, so that they were killed before they could transmit. We parameterized the model to match current understanding of *C. reductus*. Currently, the full model description and results are available in Laura Flandermeyer's Master's thesis available at the WSU thesis repository: <https://rex.libraries.wsu.edu/esploro/>.

Insecticide trials. Bioassay methods for leafhoppers were developed on a related project entitled "Insecticidal control of leafhoppers in cherries" led by co-PI Nottingham funded by the Washington Tree Fruit Research Commission. The same methods were applied in 2023 to test two rates of a new chemical, Wrath (geraniol 30%, peppermint oil 1%, cottonseed oil 0.1%, and rosemary oil 0.01%; manufactured by GroPro) in comparison with PyGanic. Data were reported in last year's continuing report for this project. In 2024, another chemical was tested, Sefina 4.89% afidopyropen and cyclopropanecarboxylate).

Results and Discussion

Model development. Leafhopper counts from sticky cards (Figure 1) and vacuum sampling (Figure 2) show similar patterns during 2022–2024. The species *C. reductus* clearly had three distinct periods of adult peaks. Phenology of *E. variegatus* was more idiosyncratic, and *C. geminatus* were too uncommonly found to visualize clear patterns. For both methods, most of the leafhoppers collected did not belong to any of these species and were probably of no concern as potential vectors of X-disease.

The best fit model for the sticky traps suggests that the *C. reductus* base temperature for development was approximately 45°F, with adult generations emerging onto traps from approximately 500 degree days (dd) to 1600dd in generation one, 1600dd to 3700dd in generation two, and 3700 to approximately 4500dd in generation 3 (Figure 3). There was significant variation between years, with 2022 typically occurring earlier in the season on a degree day scale than 2023 or 2024. This could be due to a number of reasons. First, it is possible that weather allowed greater movement in 2022 than in other years, allowing earlier movement. In addition, there could have been increased mortality in 2022 that reduced the amount of leafhopper capture later in the generations. Further research on movement and mortality, as well as evaluating counts in the 2025 data currently being collected will help identify variability in year-to-year variation.

There were some differences between the two sampling methods. Vacuum sampling seemed to have more variation in counts between samples than sticky cards, and vacuum samples tended to catch relatively more *E. variegatus* than sticky cards. Similarly, it was more difficult to distinguish between generations with vacuum sampling (Figure 4) than with sticky cards. Because sticky cards are typically used to monitor *C. reductus*, we focused modeling efforts on predicting counts on traps, allowing growers to compare counts with the model. With both methods, the three Oregon orchards tended to have more *E. variegatus*. In Washington orchards, *C. reductus* was clearly the dominant species with sticky card monitoring, whereas in Washington vacuum samples, *E. variegatus* were often found in similar or greater numbers than *C. reductus*.

Previous research suggests *E. variegatus* has a single generation in Italian vineyards (Bosco et al. 1997, Ann. Appl. Biol. 130:1), and this may also be the case in Pacific Northwest orchards.

Simulation model. The simulation model found that contrary to our hypothesis, the optimal timing for insecticide treatments to reduce transmission was when adults numbers are increasing (Figure 5). This may seem counterintuitive, given that adults may be able to transmit prior to treatment. If coverage and mortality was 100%, earlier treatment would indeed be more effective. However, with more

realistic coverage and mortality, we found that earlier sprays killed leafhopper nymphs that may have died naturally before emerging as adults anyway. By moving treatments later in the season, it targets only the leafhoppers with the greatest likelihood of transmission, reducing efforts on killing nymphs that may not have survived anyway. Thus, we recommend timing insecticides to occur when adults first start emerging on traps, which our predictive model can help detect.

The PI from 2023–2024, Dr. Orpet, departed Washington State University but remained as a co-PI on the project, and Dr. Northfield started leading in 2025 to oversee the remaining work in leafhopper quantification and model development. The datasets will be augmented by additional data in 2025 related to a Washington State Department of Agriculture Specialty Crop Block Grant project entitled “Leafhopper phenology model development and habitat assessment to improve cherry X-disease management” awarded to PI Orpet and co-PI Northfield. That grant supports technical assistance and leafhopper sampling in three-point transects within orchards: point 1 is adjacent vegetation, point 2 is the orchard edge, and point 3 is the orchard center. This expanded sampling will help us understand the role of orchard-adjacent habitat as a potential leafhopper source and its role in phenology of the leafhoppers.

Insecticide trials. Wrath, Sefina, and Pyganic, which were tested in associated with the current project in 2023 and 2024, each increased mortality to exposed *C. reductus*. A single publication that has all insecticide tests funded by WTFRC/OSCC and elsewhere has been published (Marshall et al. 2025) and information has been incorporated in the WSU Crop Protection Guide for Tree Fruits in Washington.

Resulting peer reviewed publications from this study (please contact Tobin at tnorthfield@wsu.edu if you have any difficulty accessing them):

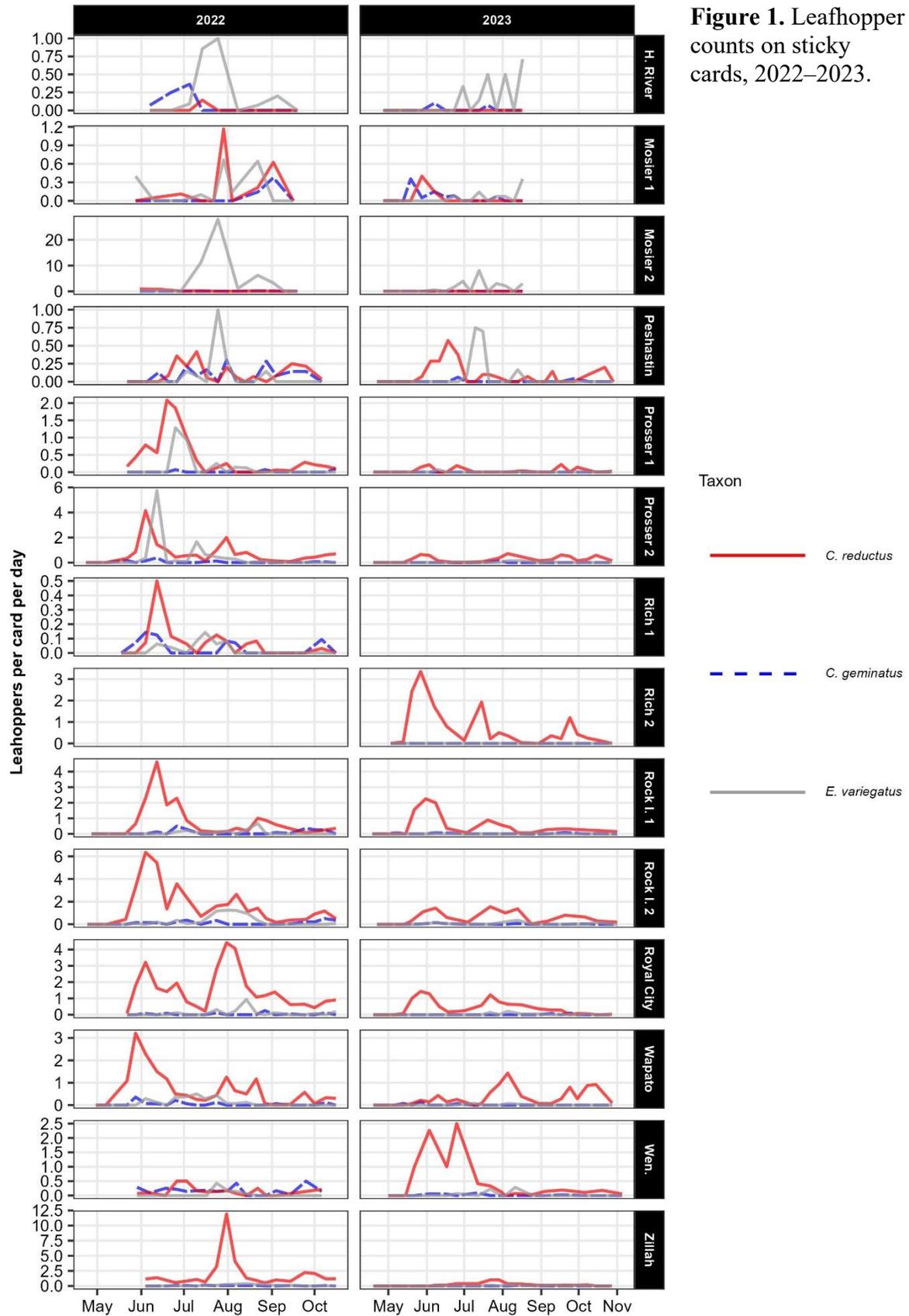
Marshall, AT, KA Catron, RJ Orpet, RT Curtiss, TD Northfield, LB Nottingham. 2025. Insecticide and repellent tests on Washington leafhopper vectors of cherry X-disease. *Journal Economic Entomology*, toaf247. <https://doi.org/10.1093/jee/toaf247>

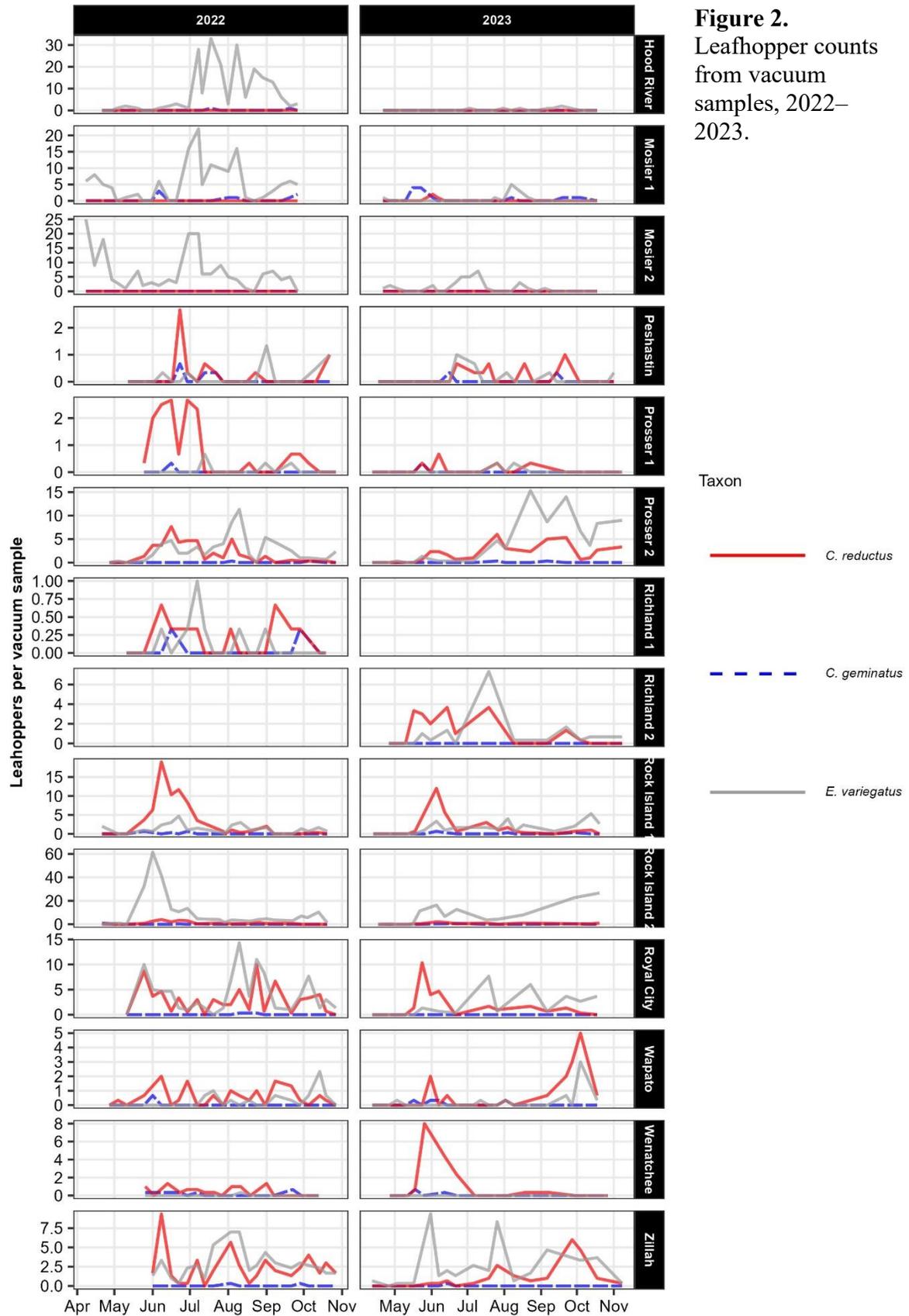
Flandermeyer, LE, LB Nottingham, SJ Harper, CG Adams, CR André, KA Catron, AE Clarke, ST DuPont, AT Marshall, TD Melton, TD Northfield. 2025. Methods for sampling X-disease *Colladonus* spp. (Hemiptera: Cicadellidae) leafhopper vectors in orchards. Washington State University. 2025. <https://doi.org/10.7273/000007491>

Clarke, AE, KA Catron, C Reyes Corral, AT Marshall, CG Adams, WR Cooper, SJ Harper, LB Nottingham, TD Northfield. 2024. *Colladonus* spp. (Hemiptera: Cicadellidae) vectors of X-disease: Biology and management in western United States. *Journal of Integrated Pest Management*, 15:13. <https://doi.org/10.1093/jipm/pmae005>

Student thesis:

Laura Flandermeyer’s Master’s Thesis:
<https://rex.libraries.wsu.edu/esploro/outputs/graduate/Sampling-and-management-of-X-disease-phytoplasma/99901125941101842>





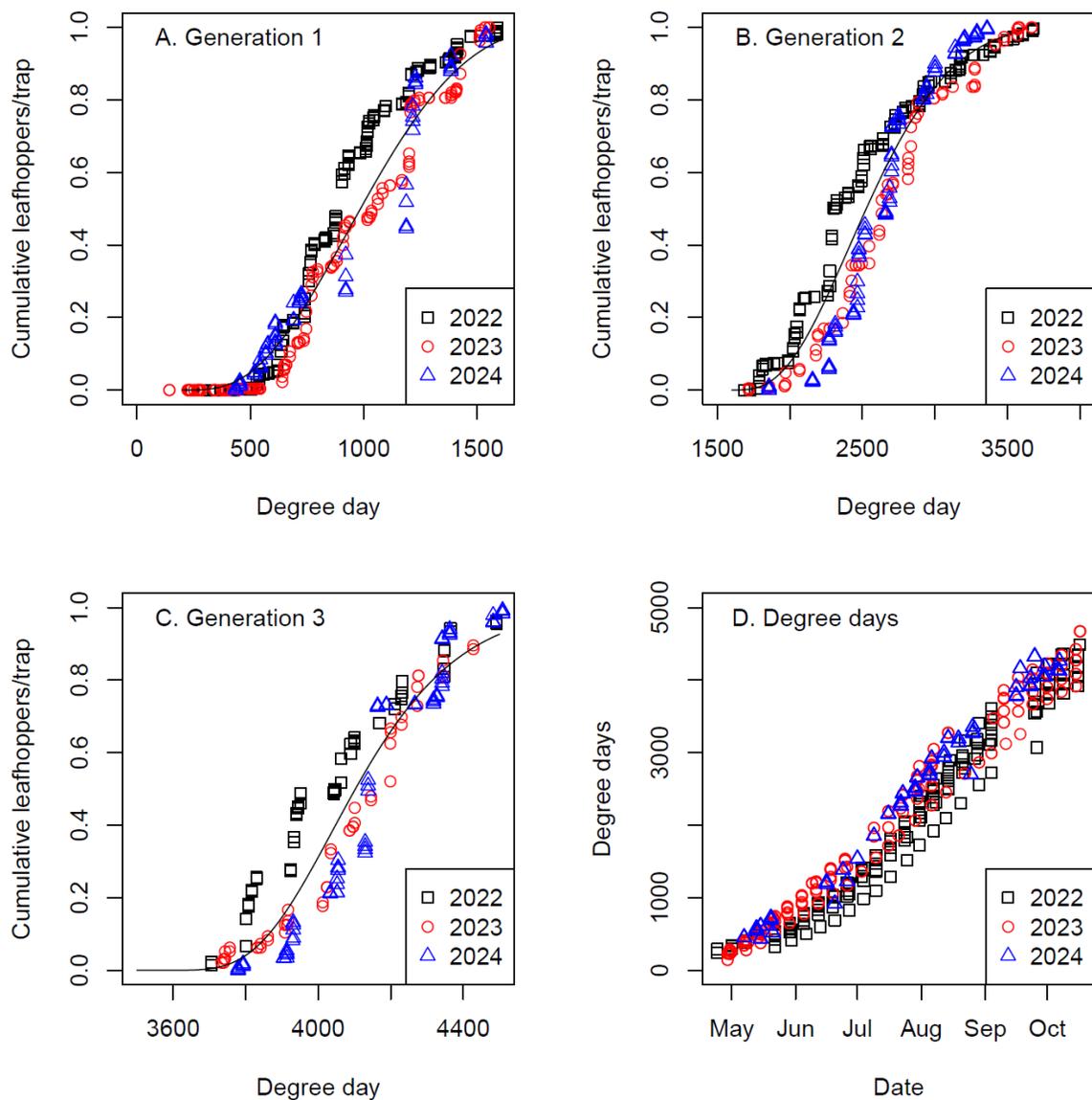


Figure 3. Data collected from sticky traps and best fit models showing three generations, occurring from approximately 500 to 1600 degree days (A), 1600 to 3700 degree days (B), and 3700 and beyond (C), along with site-specific degree day accumulation over the course of the season. The model used a base temperature of 45 degrees Fahrenheit, and are shown for 2022 (black squares), 2023 (red circles), and 2024 (blue triangles).

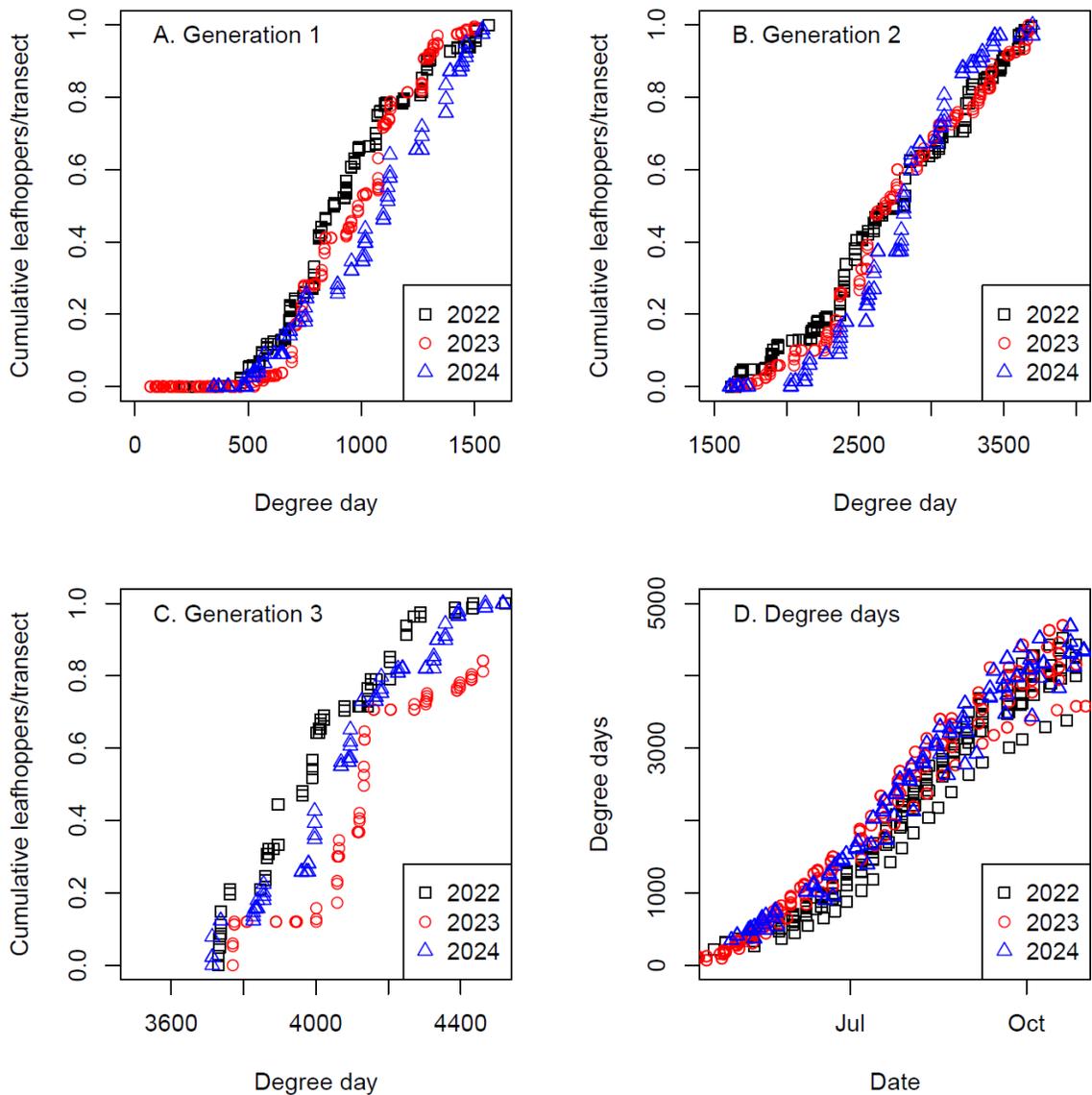


Figure 4. Data collected from vacuum sampling, showing three generations, occurring from approximately 500 to 1600 degree days (A), 1600 to 3700 degree days (B), and 3700 and beyond (C), along with site-specific degree day accumulation over the course of the season. The degree day calculation used a base temperature of 45 degrees Fahrenheit, and are shown for 2022 (black squares), 2023 (red circles), and 2024 (blue triangles).

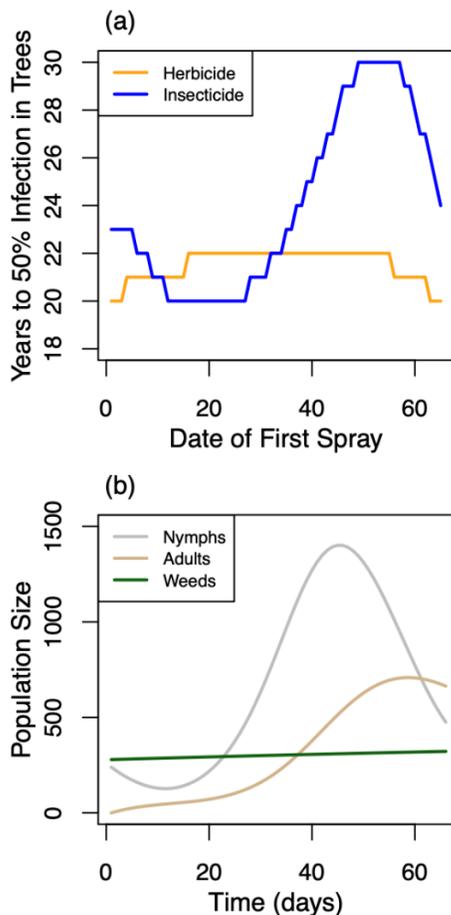


Figure 5. Optimal timing (a) of insecticide (blue) and herbicide (orange) in simulation models that maximizes orchard longevity, relative the relative abundance of nymphs (gray), adults (goldenrod), or weeds (green). Time is presented relative to the start of a given generation, and is most useful in comparison to the leafhopper stages present. Insecticides were assumed to be effective on each nymphs and adults, with 80% coverage.