

Proposal Title: Assessing effects of orchard management on codling moth ecology

Report Type: Final

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Project Duration: 3-Year

Total Project Request for Year 1 Funding: \$82,000
Total Project Request for Year 2 Funding: \$85,000
Total Project Request for Year 3 Funding: \$88,000

Other related/associated funding sources: None

WTFRC Collaborative Costs: None

Budget 1:

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Item	2022	2023	2024
Salaries ¹	\$58,000	\$60,320	\$62,733
Benefits ²	\$20,671	\$21,498	\$22,358
Wages			
Benefits			
Equipment			
Supplies ³	\$1,329	\$1,182	\$909
Travel ⁴	\$2,000	\$2,000	\$2,000
Miscellaneous			
Plot Fees			
Total	\$82,000	\$85,000	\$88,000

1 – Salary for a postdoctoral scholar (100% FTE) who will oversee the project

2 – Benefits for the postdoctoral scholar include health and life insurance, retirement benefits, etc.

3 – Funds to purchase trapping materials for collection of codling moth data

4 – Funds will be used to support rental of a motor pool vehicle to support regular travel to field sites

A. Justification

Effective codling moth management relies on assessing population dynamics and phenology in orchards. For example, growers and consultants use phenology models to estimate the timing of codling moth life stages in the field so insecticide sprays are timed to when eggs and new larvae are present. However, the validity of codling moth models has been questioned recently because codling moth trap catch data from commercial orchards often fails to mirror predictions from models; ***growers and consultants often note in particular that trap catch of first-generation adults lags what is predicted by phenology models.*** In this project we are assessing factors that affect codling moth ecology and the potential fit (or lack thereof) between trap catch and predictions of phenology models. ***Our project will produce more flexible models that growers can use to assess codling moth ecology and make management decisions.***

B. Objectives

Our project used a variety of data sources to build more effective tools to assess codling moth ecology in orchards. Our three complementary objectives were:

- (1) Assess dynamics of codling moth populations across orchards with variation in management
- (2) Improve predictive capacity of codling moth phenology models
- (3) Conduct outreach related to codling moth population modeling

C. Progress on Objectives

(i) Summary. Our study focused on providing a better understanding of codling moth ecology to predict dynamics in orchards. To complete the project, we hired two postdoctoral scholars (Rob Curtiss and then Diego Rincon) who lead on research objectives with support for outreach and data science. Over the course of the project we were able to gather large field datasets on codling moth from commercial orchards through our own field sampling and through collaborations with producers and pest-control advisors. We used these data to validate and test phenology models and build new tools that assess codling moth flight. Our project can aid producers understand how phenology models can be validated with field trapping data.

(ii) Objective 1: Assess dynamics of codling moth populations across orchards with variation in management. From 2022 to 2025, we gathered data through our field work and by working with commercial producers and pest control advisors from the state of Washington and the OK-SIR program in British Columbia. The complete dataset is made of over 3 million records and was used to measure the population dynamics of codling moth across production orchards that vary considerably in management tactics. Using these data we assessed the lag that producers often see between predictions from the phenology model and moth captures in traps, and we then built a series of models to attempt to predict future codling moth abundance based on degree days and trap catch. In our approach, early trap catch data is input into a model and an estimate of the population dynamics is generated based on projections of phenology and past captures. We further tested models to estimate how codling moth flight dynamics might be impacted by weather variables; these models have been incorporated into the WSU Decision Aid System and are being used by producers and pest control advisors as part of their management tactics.

Field population dynamics assessments. In the first year (2022), Robert Curtiss, a postdoctoral scholar in Entomology, led the sampling effort for the project. Our goal was to sample codling moth populations across orchards that reflected variability in production conditions and management practices used in Washington (i.e., across gradients from North to South, and East to West, with variable elevations, weather, etc.). We achieved our goals except we were unable to identify any orchard blocks that had no mating disruption or early-season insecticides; while our study thus lacked a true “untreated control”, we felt confident our sites reflected practices in Washington orchards. During 2022, our team conducted weekly sampling of codling moth in each orchard with a total of ten pheromone traps that were placed both along block edges and towards the center (Fig. 1). We used Orange Pherocon VI delta traps baited with a PHEROCON® CM-DA COMBO™ Lure + AA Lure (Trécé, Inc.) to attract both male and female moths. Traps were placed within the top 1/3 of pre-marked trees and lures were changed every eight weeks, and traps were monitored every 7 days. Due to the proximity of sterile moth releases, all captured moths were inspected for the presence of internal red dye to discern sterile from wild moths. From this first year of data, codling moth were rare across our 7 orchard blocks, with only 360 total moths collected across all sites; only 20% of the moths collected were wild type moths and 80% sterile moths. These data provided a basis for modeling, but more data were needed and were then the focus of our project in 2023 to 2025 (see below).



Fig. 1. Example of sampling design in a Washington apple orchard. Traps were placed throughout the block and were checked weekly to assess adult codling moth population dynamics.

Data collection from 2023 to 2025. To supplement our field work conducted in 2022, in the past three years we hired a second postdoctoral scholar (Diego Rincon), who took over the project as a data scientist and Curtiss moved into a collaborator role as he took over other projects. Over these years we gathered more field data ourselves and by working with commercial producers in Washington and the OK-SIR program in British Columbia. Through these commercial partners we gathered a considerable amount of additional trap data from fields managed with variability in sterile insect releases and insecticides (Fig. 2). We were able to gather data from 287 sites with weekly sampling of at least 10 pheromone traps to complement our field survey. Our datasets represented areas with variation in trap density (Fig. 2), which could affect the probability that we are able to accurately estimate abundance of codling moth populations. When we combined field data from our own trials with data from our commercial partners, we were able to graph how variable codling moth trap catch actually is within fields (Fig. 3). In Fig. 3, we show both the phenology model for codling moth (blue line) as well as a model fit to the trap catch data (black line). This shows that in real-world orchards it is common for the phenomenon that growers will see a lag between when the phenology model predicts moths are initially active and when they are actually caught. This means that the phenology models is accurate, but that variability in sampling dynamics and population abundance affect the value of trap data in making population assessments based on real world data.

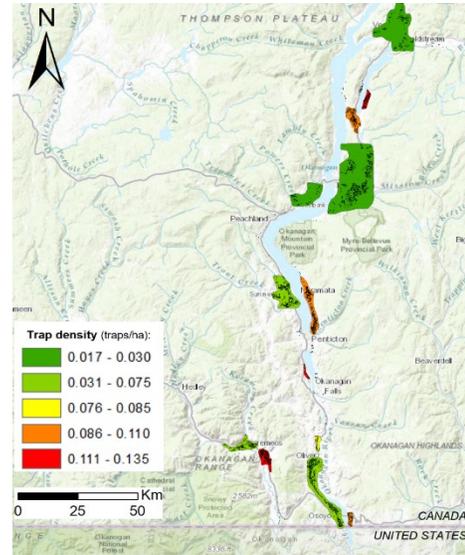


Fig. 3. Location of trap sites in British Columbia where data was collected to complement data from orchards we sampled in Washington State

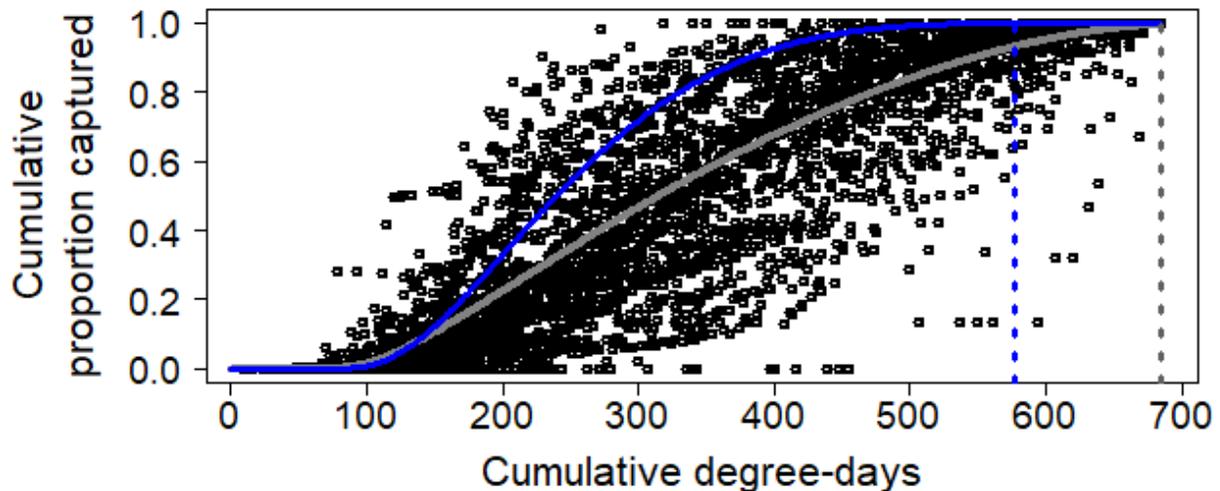


Figure 3. Data from over 280 sites showing trap catch of codling moth adults over the first generation. The blue line shows the phenology model used on the WSU DAS (Jones and Wiman 2012), and the gray line shows a population dynamics curve fit to the data. The difference between the lines shows the typical lag in when adults are captured in traps compared to when a phenology model predicts they are emerging.

Population modeling. In 2023 we brought on postdoctoral scholar Diego Rincon to work on the modeling parts of the project. Our goal was to use data from the field sampling to determine if we could make projections of future codling moth population size from trap-catch data. Using the field data, we compared parameters associated with the phenology model for codling moth used on DAS with those from a new model describing field-level population dynamics (Table 1, Fig. 4). One of the main takeaways is that growers or consultants may see up to a 100DD lag in when adults are collected compared to when they may emerge. This reflects variability in our ability to trap codling moth in orchards; from our data we were able to estimate we catch far fewer than 1% of total moths in orchards, even with high trap density (Fig. 4).

Table 1. Coefficients used in the Johnson SB distribution function to predict codling moth adult emergence and capture in pheromone traps as a function of cumulative degree-days.

Model	Parameters				Reference
	γ	δ	ξ	λ	
Phenology model	1.073	1.239	69	577.2	(Jones and Wiman, 2012)
Pheromone capture model	0.460 (SE = 0.170)	0.867 (SE = 0.094)	69.220 (SE = 7.573)	662.6 (SE = 33.366)	This study

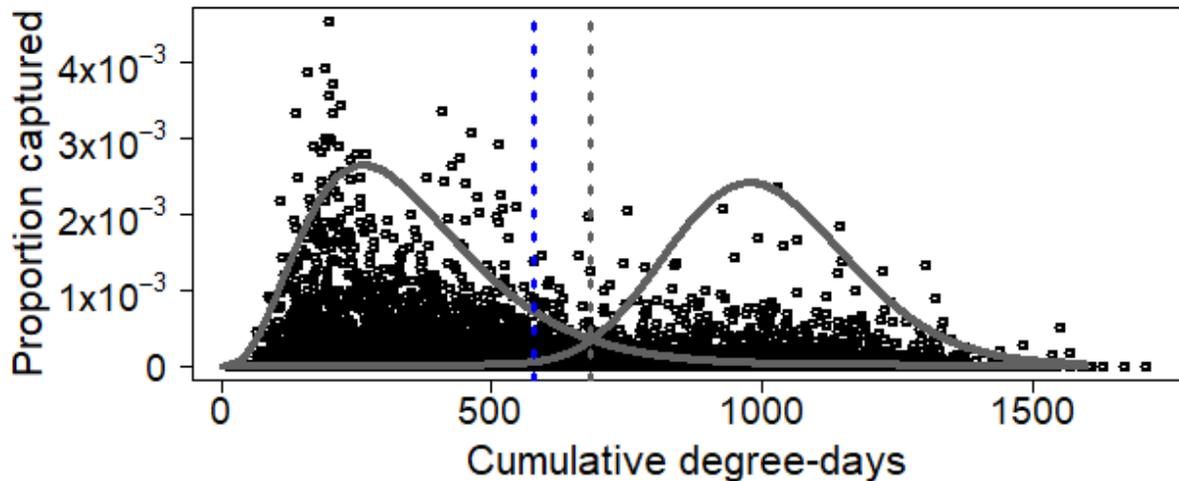


Fig. 4. Estimated proportion of codling moth caught in traps across the first and second adult generations

We build on our population dynamics analysis to build a series of models to attempt to predict future codling moth abundance based on degree days and cumulative trap catch (Fig. 5). In our approach, trap catch data can be input into a model and an estimate of the future phenology and population dynamics is generated (blue and red lines in Fig. 5). We then use variance in the trap catch data to estimate a 95% confidence interval for the future growth of the population (dashed lines in Fig. 5). In areas with greater trap density, or where codling moth populations are more abundant, our ability to catch early-emerging moths increases. In such areas, the confidence intervals should shrink compared to sites with lower trap density. Regardless, our approach can be used to model population dynamics by combining phenology and trap catch.

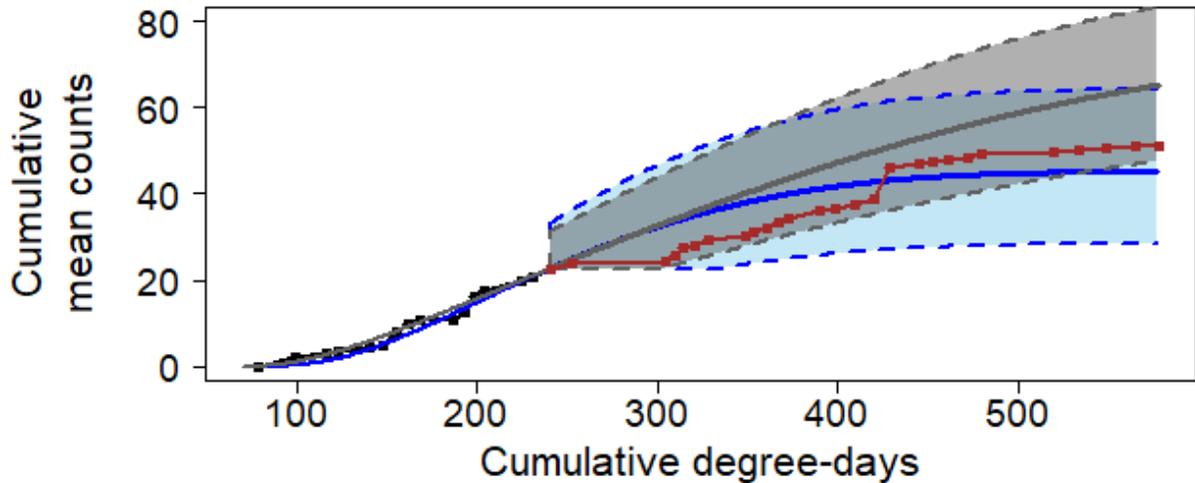


Fig 5. Example of our modeling approach to predict future codling moth abundance based on phenology and ongoing sampling. In this example, data is collected in traps up to 250 degree days (black squares), and a cumulative count of moths is made. At this point, both a phenology (blue line) or population dynamics (red line) models are fit to the trap data, and variance in the trap catch is used to estimate future 95% confidence intervals. After this point, future trap catch can be monitored to validate the model.

Validation of predictions. Sensitivity analyses showed the model was robust for a wide range of sample sizes, codling moth densities, and management scenarios, with prediction accuracy for long-term outputs (prediction lengths >120 degree-days) ranging from 69 to 94% (Fig. 6). Overall, our approach suggests we may be able to predict future codling moth densities.

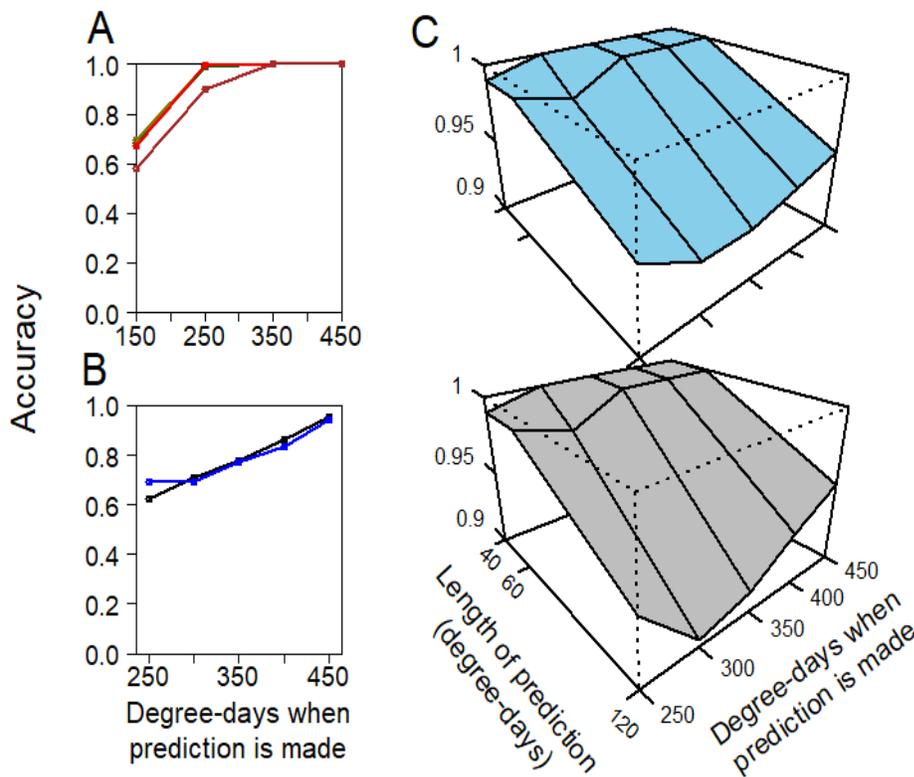


Fig. 6. In panels A and B, accuracy (the proportion of predictions that fall in a prediction band) of models used for codling moth. Model accuracy is shown as a function of degree-days when predictions are made; each line represents a sample size. In panel C, blue and grey surfaces represent the accuracy of predictions for two model types

We also gathered a dataset from seven orchards in WA with detailed information about trap location and density, with four years of weekly trap data, to further validate the model (Fig. 7). We found that the model closely resemble the data collected in Washington (Fig. 8). Also, after running a new validation analysis with the new data, we found our model maintains accuracy close to 80% (19% average error) when predictions are made at 350 degree days.

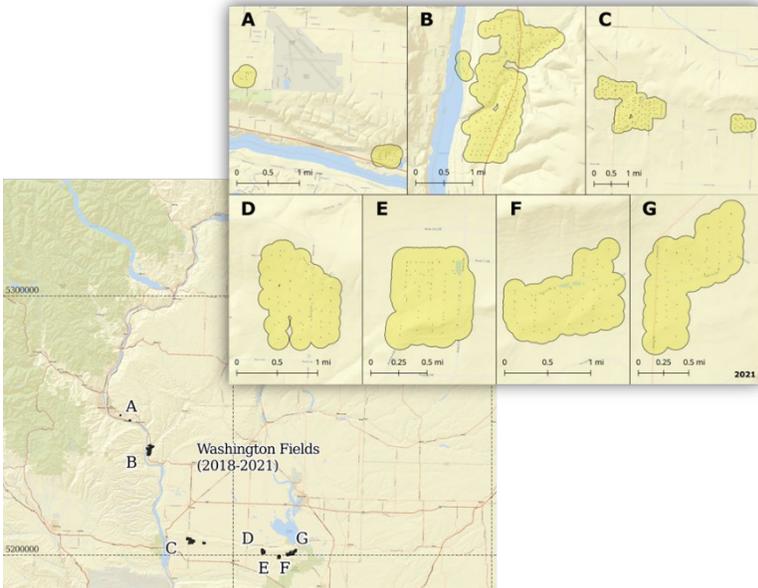


Fig. 7. Location of seven orchards from which new data was collected to further validate the codling moth forecasting models and evaluate the effect of trap density on moth capture efficacy and prediction. Sites varied both in configuration and the trap density. Data at each site was collected weekly for a four year period, and weather data from each site was also collected.

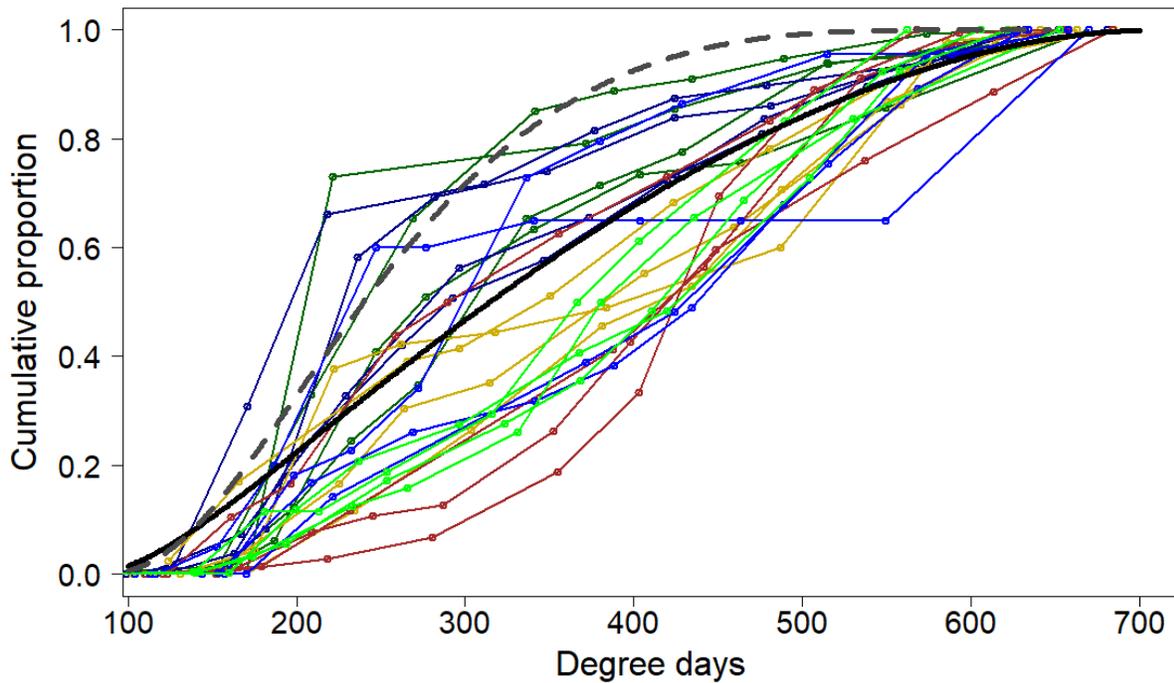


Fig. 8. Cumulative proportion of moth captures in pheromone traps for the first generation of the codling moth in seven WA orchards. Each broken line represents the average of captures in an orchard and year, and orchards are represented with different colors. The black solid curve represents the model fit to the OK-SIR dataset and the grey dashed curve is the phenology model used in WSU DAS.

(iii) Objective 2: Improve predictive capacity of codling moth phenology models

In the last two years we assessed how codling moth populations are affected by intensity of mating disruption and insecticide use (common programs in Table 2), and we built models to show when these treatments should affect population dynamics (Fig. 9).

Table 2. Treatment programs and expected efficacies used to assess the codling moth models

Treatment program	% survival per spray	% overall survival	No. of sprays	Timing (in degree-days)		
				First	Second	Subsequent
Conventional traditional	10, 10	35.5	2 larvicides	235	368 (14 days)	-
Delayed first cover	20, 10, 10	7.74	Oil and then 2 larvicides	210	290	423 (14 days)
Mating disruption †	-	75.49	-	-	-	-
Organic traditional ‡	30, 30, 30, 30	40.9	4 virus sprays	235	+7 days	+7 days

† The overall survival of mating disruption programs depends on temperature

‡ The organic traditional treatment program is deployed in addition to mating disruption

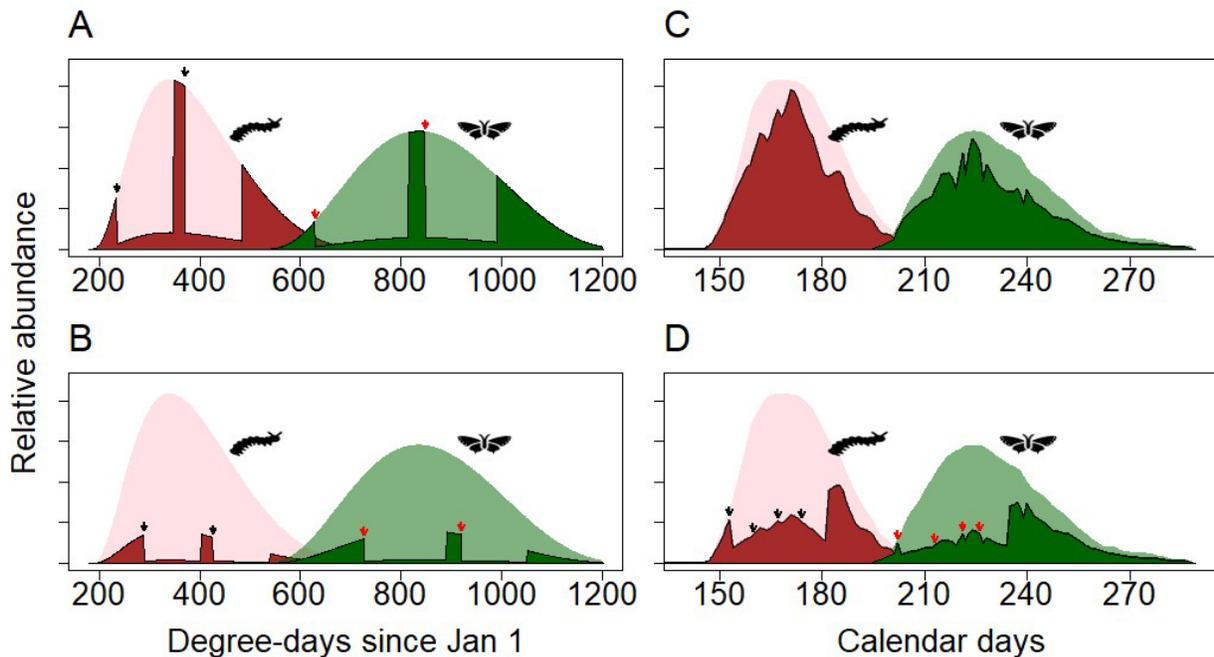


Fig. 9. Theoretical effect of four treatment programs on the codling moth larvae (brown for treated vs. pink for untreated) and adults (dark green for treated vs. light green for untreated) for the first summer generation: (A) conventional traditional, (B) delayed first cover, (C) mating disruption, and (D) mating disruption plus organic traditional. The black arrows indicate the timing of insecticide treatments and the red arrows the corresponding start of the effect on adult emergence.

The models about the theoretical effect of insecticide applications and mating disruption on codling moth phenology were used to assess the effect of control treatments on codling moth populations. Results show that our model can distinguish pest populations that have been treated with control treatments that are >50% effective from pest populations treated with less effective controls. We also found that it is more challenging to detect efficacy of mating disruption programs compared with pesticide-based programs.

We built on our analysis by gathering weather data associated with all of our sites, and began to build and validate a model that assesses how codling moth flight varies based on temperature, wind, and rain. Trap captures may be delayed, even when moths have emerged, if the conditions in an orchard on a particular day are not suitable. The flight model has been built into the DAS and is being further validated based on data from our users (Fig. 10).

Flight Chart ?

NEW

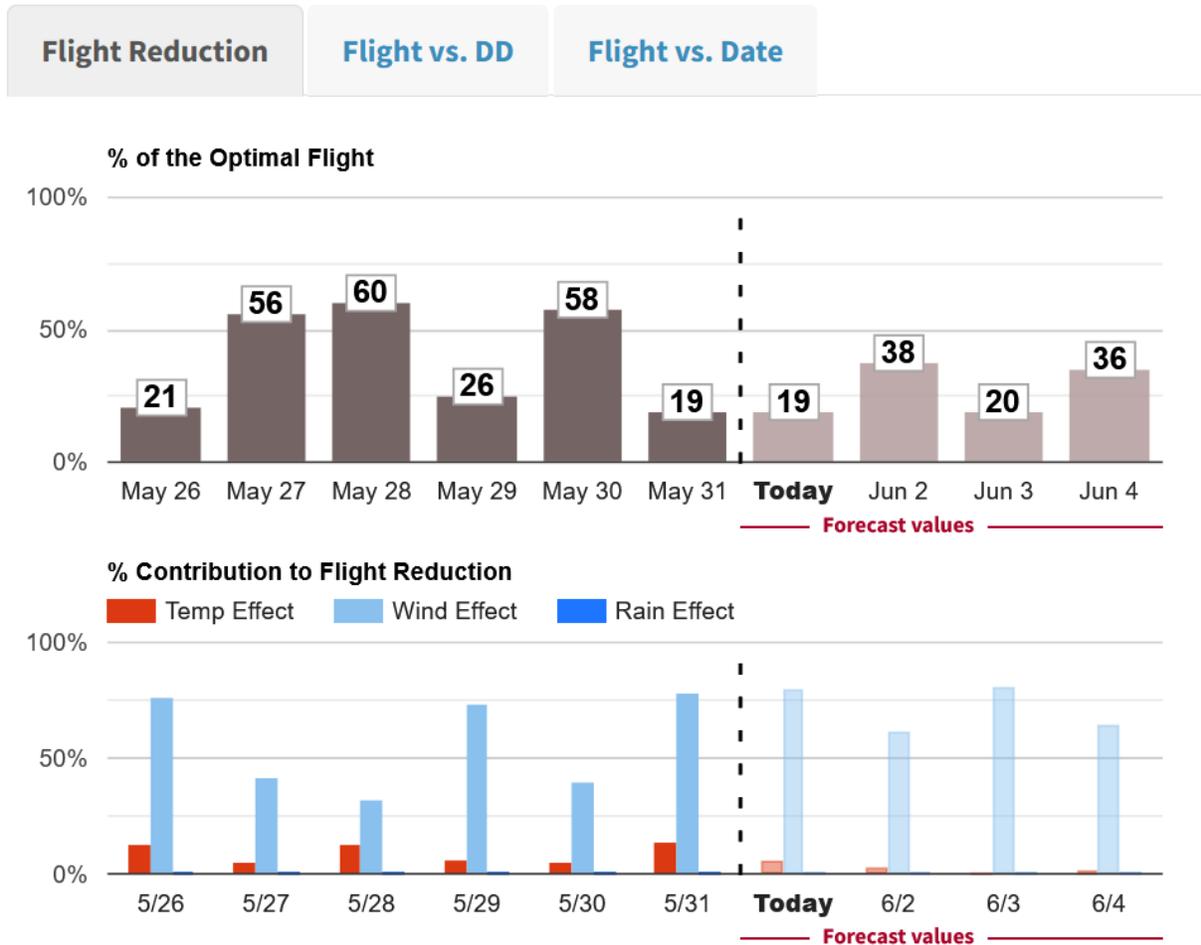


Fig. 10. Output of codling moth flight model shown on the WSU Decision Aid System, which uses site-specific data on temperature, wind, and rain to predict flight parameters.

(vi) Objective 3: Conduct outreach related to codling moth population modeling. Over the entire project we ran workshops, both in person and digital, primarily from January to April to talk about how codling moth models are run and interpreted. These workshops were attended by approximately 100 individuals in total, who spent 20+ hours with our team discussing codling moth models. Our team members also traveled regularly to production orchards in each year of the project to learn from pest control advisors and producers on their practices and how we can better build models to guide management. The flight model in fact came out of conversations we had with members on industry. We also gave talks at the meeting of the Entomological Society of America in 2024 and 2025.

Executive Summary

Project Title: Assessing effects of orchard management on codling moth ecology

Keywords: Codling moth, mating disruption, management, phenology, population dynamics

Abstract: This project was designed to provide information about how producers and pest control advisors can better manage codling moth by linking predictions of phenology models with trap catch data. While much of the Washington tree fruit industry uses phenology models in their codling moth management, it is often unclear how growers should integrate trap catch data with models to make spray decisions. Our project provided data on the variability observed in codling moth populations across realistic Washington growing conditions, and showed how trap catch data may not always mirror predictions of phenology models. We showed that effective early season management using mating disruption, insecticides, or sterile insect releases may actually cause observed trap catch to lag considerably from what is predicted from models. We also found that weather variables like temperature, wind, and rainfall affect the flight conditions of codling moth, and we used these data to build better codling moth models. We integrated this information into the WSU Decision Aid System to provide better models that allow growers to conduct more responsive management that links real-time trap data with models.

Our work from 2022 to 2025 used data from field sampling in Washington orchards along with data from commercial orchards in Washington and British Columbia. From these data we made considerable progress on showing how phenology models can be used to accurately predict codling moth population dynamics (i.e., abundance) based on variable management scenarios. Our project supported two postdoctoral scholars, undergraduates, and permanent staff who conducted the field work, modeling, and outreach. Our team also continued to build a more informed user base for the digital tools built into the WSU Decision Aid System.