FINAL PROJECT REPORT

Project Title: Development and validation of pest and natural enemy models

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Cooperators: Betsy Beers, WSU-TFREC

Percentage time per crop: Apple: 50 Pear: 20 Cherry: 20 Stone Fruit: 10

Other funding sources

Agency Name: WSU-Extension
Amt. awarded: $266,344
Notes: The amount funded is the contribution that WSU-Extension provides for DAS support and maintenance + an additional 1 FTE for a second programmer for one year.

Total Project Funding: **Year 1:** 75,154 **Year 2:** 78,160 **Year 3:** 81,306

Budget History

Item	**2014**	**2015**	**2016**
Salaries[1]	42,129	43,814	46,354
Benefits[2]	14,983	15,582	16,668
Wages	12,480	12,979	12,480
Benefits[3]	262	273	300
Equipment	0	0	0
Supplies[4]	2,500	2,600	2,704
Travel[5]	2,800	2,912	2,800
Miscellaneous	0	0	0
Plot Fees	0	0	0
Total	75,154	78,160	81,306

Footnotes:
[1] U. Chambers Y1-3 (0.5 FTE); T. Melton Y1-3 (0.25 FTE)
[2] 33.5%
[3] 2.1%
[4] includes lab and field supplies
[5] w/in state travel

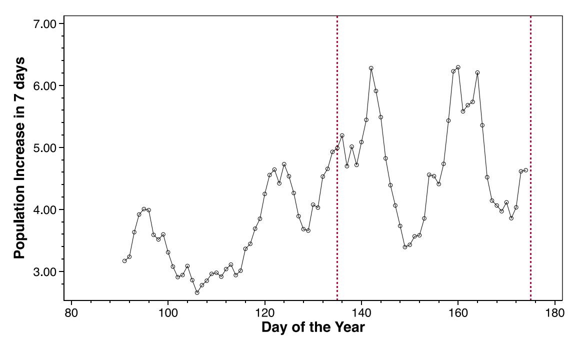
Objectives:
1. Develop models for mites and aphids using literature data and validate the information as needed.
2. Validate natural enemy models already developed in the SCRI biological control grant.
3. Re-evaluate the San Jose scale model and its biofix and accuracy.

Significant Findings:

- We developed models for two-spotted spider mite, European red mite, woolly apple aphid, green apple aphid, rosy apple aphid, and the western predatory mite that predict the population growth rate throughout the season
- Our field surveys showed both RAA and Apple grain aphid populations tend to be restricted to narrow windows in time in the field.
- Breaking diapause by two-spotted spider mite in the spring was shown to be predictable by photoperiod alone; this gives us information on the development of their populations that are critical for management
- We completed phenology models for the following natural enemies over the course of the grant: *Deraeocoris brevis* (a predator of spider mites, aphids, and pear psylla), the WAA parasitoid *Aphelinus mali*, the syrphid fly, *Eupeodes fumipennis* (aphid predator), and the green lacewing, *Chrysoperla plorabunda* (generalist predator on aphids, mites, soft-bodied insects).
- The current San Jose scale model was significantly improved and does a good job of predicting the second crawler generation and no longer requires a biofix

Objective 1. Develop models for mites and aphids using literature data and validate the information as needed

Fig. 1. Population growth rate for RAA using data from WSU TFREC in 2014. Dotted lines indicate time for greatest numbers found in the orchard.

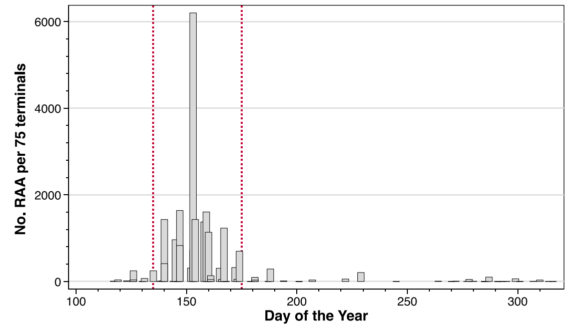


Over the course of the grant, we have developed models from literature data to predict population growth for two spotted spider mite (TSSM), European red mite (ERM), woolly apple aphid (WAA), green apple aphid (GAA), rosy apple aphid (RAA), and the western predatory mite (WPM), *Galendromus* (=*Typhlodromus*) *occidentalis* (see Fig. 1 as an example). These models do not predict phenology, but as we collect more data, we should be able to develop the models further. The RAA, GAA, ERM, TSSM, and WPM models have been developed into complete life tables that can easily be converted to demographic degree-day models that can predict pesticide effects as soon as we get the phenology quantified.

Rosy apple aphid
We have been collecting data in the field since 2015 to provide the actual phenology of the different stages so that we can make this into a pesticide effects model, but need more data for complete validation. However, there is considerable information that our field studies have generated that provide us with information that insights into the population dynamics.

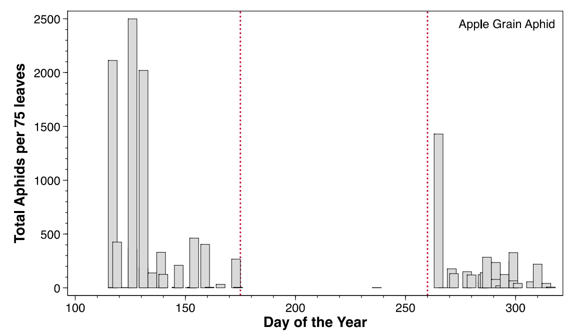
Our data this past two years where we randomly chose trees and estimated the population levels showed that 92.4% of the total number of RAA found were found between 14 May and 24 June at all locations (Fig. 2). Winged adults were commonly found during this period as well as throughout the summer in very limited numbers. In 2016, we also performed a targeted sample after 24 June where we specifically looked for RAA by examining each tree for presence of WAA before sampling. When we compare the two sampling types, we found that the targeted samples detected 7-fold more RAA throughout the summer compared to the random samples. The samples also showed that the winged forms appeared at the same time as the wingless forms throughout the summer, generally in multiples of 270 DD apart (≈immature development period). Samples in the future need to be taken more frequently to adequately characterize the phenology. In addition, we need to collect overwintering eggs in the spring to evaluate hatching which our data summary suggests should be predictable.

Fig. 2. No. RAA per 75 terminals found over the last two years at 3 different orchards. Dotted lines show the populations between 14 May and 24 June.



The numbers throughout the season suggest that controls should not be orchard-wide except during the period of early population growth (14 May to 24 June). Populations after this point are sporadic and highly clumped, which suggests that only spot treatments or use of natural enemy attractants would be sufficient for population control. Movement back into the orchard from the summer hosts starts in the late season (after first week of September), but populations are low enough at that time that they would not be easy to treat. In addition, they come in over a fairly long period which would make it harder to target the populations.

Fig. 3. Phenology of AGA over the years 2014-2015 at 3 different orchards in NCW. Dotted lines at 24 June and 15 Sept.



Apple Grain Aphid
The literature data on the AGA has not been synthesized at this time. However, our sampling for RAA also provided information on AGA phenology. Similar to the RAA, the populations of AGA are most abundant early in the season and by 24 June they also moved out of the orchard and moved back into the orchard in much higher numbers starting at about the same time (first-second week of September) as RAA. In between those dates, AGA was not found in any significant numbers in any of the six orchard/years of data (Fig. 3).

Green Apple Aphid
Our data for GAA are much more complete than for either the RAA or AGA. Unlike the other two species, the GAA is found in the orchard throughout the season in very high levels and does not move out of the orchard during the summer (Fig. 4). We still have a significant amount of analysis to do before we can estimate the phenology, but will be working on this over the next few months.

Effect of leaf age on aphid populations

Literature data suggests that aphid population growth is heavily influenced by whether the foliage is young and quickly growing or starting to age and hardened off. We classified all the terminals as either young and expanding, and then categorized the aphid populations as 0, or >5 per leaf. For the GAA and RAA, there were significantly higher aphid populations on younger leaves. However, for the AGA, higher populations were found significantly more often on the older leaves.

Mite models

The data from 2014-2016 show that diapause for the two spotted spider mite (TSSM) is broken by photoperiods >13.3 hours long (Fig. 5) which happens roughly around the third week of March (in NCW) depending on the latitude. The studies for the egg hatch of European red mite egg hatch did not work well and need to be re-done. We ran studies in 2014 that showed the emergence was about 30% longer than literature data indicated and when they were repeated in 2016, there was a problem with the photoperiod where it was not changed over the course of the experiment to correspond to the outside conditions. That resulted in the egg hatch period being greatly expanded, well beyond compared to what would be reasonable. Examining egg numbers in the field taken at weekly intervals did not clarify the issue. We will collect egg masses at different times very early in February and continuing weekly until late April, bring them to the lab, and put them in a growth chamber with a constant temperature, but photoperiod adjusted weekly to the average of the outside photoperiod. This will allow us to determine how the egg hatch changes with photoperiod and whether we can predict egg hatch to help clarify the best ways to control the eggs and resulting adults.

We did develop population growth models to determine how fast the population develops over the season for both TSSM and ERM, and our data show that the TSSM growth is about 25% higher and developmental rate is about 25% quicker at any time during the season than ERM, suggesting it would be more of a problem when it is present. However, because the populations start at different stages in the spring (ERM as eggs, TSSM as adult females in diapause), there are differences which affect the generalization particularly at the start of the season.

Fig. 4. GAA phenology over the years 2015 and 2016 at 3 orchards in NCW.

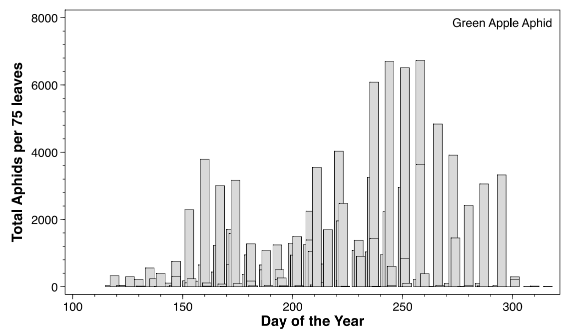
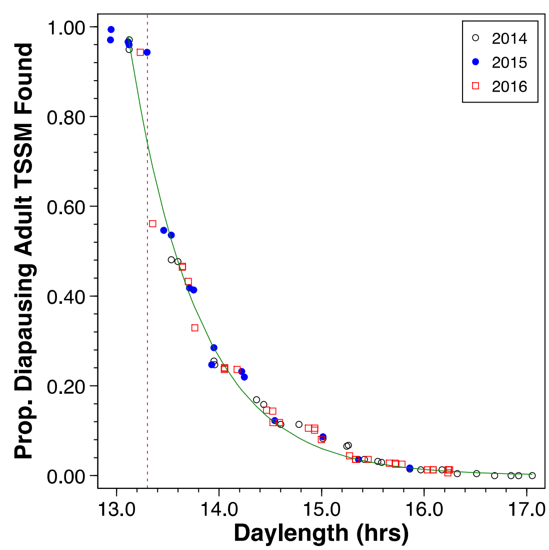


Fig. 5. Proportion of diapausing adult TSSM over a three-year period at x different orchards as day length changes in the spring. Dotted line shows the rapid drop at 13.3 hrs daylight, which corresponds to late March in NCW.

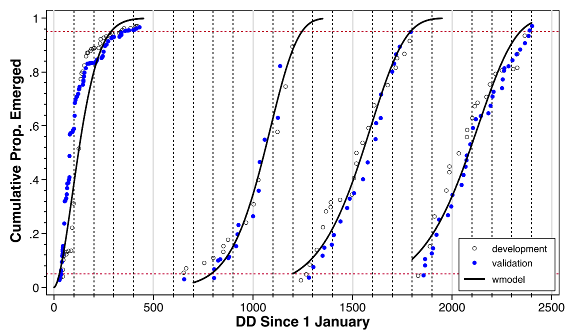


Obj. 2. Validate natural enemy models already developed in the SCRI biological control grant.

Over the course of this grant, we have completed models for the syrphid fly (*Eupeodes fumipennis*), the green lacewing (*Chrysoperla plorabunda* (=*C. carnea*)), the predatory bug, *Deraeocoris brevis,* and the parasitoid of the woolly apple aphid, *Aphelinus mali*. The models predict phenology of the adult stage for the syrphid, *Deraeocoris*, and *A. mali*, and all stages for *C. plorabunda*. We are still working on the *Deraeocoris* model and hope to have it developed into a pesticide effect model, similar to those for codling moth, OBLR, PLR, and the two lacewings (*Chrysopa nigricornis* and *C. plorabunda*). We hope to complete this in the spring and it will be part of the training system that will allow the user to evaluate spray programs on pests and the natural enemies that are being developed over the next three years on a WSDA/USDA block grant already funded.

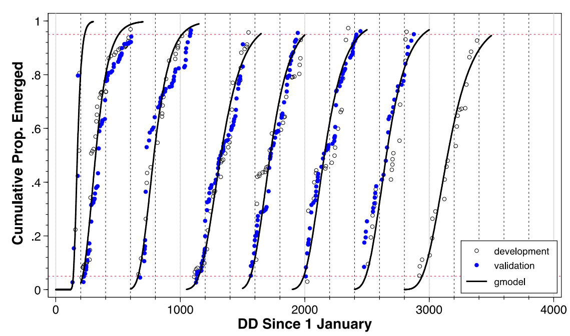
All of the models have been previously reported on except the *Deraeocoris* and *A. mali* models. We found that the lower threshold was 50 °F and the upper threshold was 88°F and uses a horizontal cutoff – the same DD calculations as codling moth. *Deraeocoris* overwinters as the adult stage underneath the bark scales, and the overwintering emergence starts almost immediately and is mostly complete by 400 DDF, with immatures starting to occur fairly quickly and give rise to the first summer generation adults around 700 DDF. We had enough data to model the first four generations (overwintering and 3 summer generations) (Fig. 6); there are probably more generations in warmer years, but we don't have enough data to model those other generations at this point.

Fig. 6. *Dereaocoris brevis* adult phenology over a six year period from 24 orchard/years data. Open circles are from the model development data set and solid circles from the validation data set.



The *Aphelinus mali* (parasitoid of woolly apple aphid) model provides phenology for each adult generation and we found at least 8 generations per year. The first generation is very short, primarily because they overwinter in the pupal stage, but after that, the generations are separated by about 450 DD (length of the egg-adult stage) (Fig. 7). Phenology was very similar between the developmental and validation data sets. We are not sure if we can develop this into a pesticide effects model yet, we will work on it in the spring.

Fig. 7. Phenology of adult *A. mali* over a six-year period from 24 orchard/years data. Open circles are from the model development data set and solid circles from the validation data set.

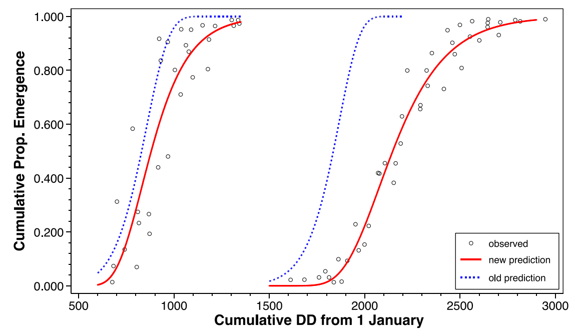


Objective 3. Re-evaluate the San Jose scale model and its biofix and accuracy.

The San Jose scale model suggested that the codling moth biofix be used to predict the first flight of males. Unfortunately, males are hard to capture reliably because they are small, fragile, and don't fly well if any wind is present. However, the target for spray programs is actually the crawler stage, so predicting the emergence of crawlers is of greater importance for IPM. The model used on DAS was the old PETE model from Michigan State University and studies done in California and Washington.

To test the model and update it as needed, we collected SJS crawlers (and adults) using double sided sticky tape placed around infested branches during the years 2014-2016 at three different orchards. Tapes were replaced weekly and the number of crawlers were recorded for each orchard/year combination.

Fig. 8. Comparison of the old and new San Jose scale models for predicting crawler emergence.



Results & Discussion:

Our data showed the current model, even when updated with the codling moth biofix did not predict the crawler emergence well (Fig. 8, dotted line). In general, the old model predicted first crawler generation earlier than observed in our studies, although the shape of the distribution was similar. The second generation was considerably earlier and had a much shorter window of emergence than what we observed. Some of the difference in the window of emergence may have to do with our warmer spring and summer periods that would tend to make a greater percentage of the population miss the diapause triggers that may be important in cooler years. However, the big discrepancy in our situation and the old model means that if the second generation had ever been targeted (**note: DAS never reported or suggested controls for the second generation)** using the model timing, it would have been way too early to have any impact on the population.

Our new model predicts the emergence of both crawler generations with greater accuracy than that of the old model (Fig. 8). Control recommendations in DAS will be updated with the new model and remain concentrated on the first crawler generation. However, we can also make some recommendations for timing of the second generation if the first generation was missed and populations are high. This would not normally be a good target, because by this time crawlers may have already moved to the fruit, but as a rescue treatment, it might be a useful strategy.

Executive Summary:

The work done on this grant has provided a number of new tools that greatly improve our ability to predict the best times for management and times to withhold treatments because of their impacts on natural enemies. In addition to the development of various models, we have also clarified areas where we need more information to complete models for different pests.

Overall, the grant provided six new population growth models for Green apple aphid (*Aphis pomi*), the rosy apple aphid (*Dysaphis plantaginea*) the woolly apple aphid (*Eriosoma lanigerum*), two-spotted spider mite (*Tetranychus urticae)*, European red mite (*Panonychus ulmi*), and the western predatory mite (*Galendromus* (=*Typhlodromus*) *occidentalis*). Combined with what we already have in terms of phenology and what we hope to gain over the next few years, we should be able to clarify the best management timings and needs.

In terms of validating a series of natural enemy phenology models developed previously from our SCRI biological control grant, we were able to validate four of those models. The model for the green lacewing *Chrysoperla plorabunda* has already been developed into a pesticide effects model (similar to those already developed for codling moth, *Pandemis* leafroller, oblique-banded leafroller, and the lacewing, *Chrysopa nigricornis*), and we will be working on the development of those models for *Deraeocoris brevis* and *Aphelinus mali*. If those models can be developed, we will have a robust picture of how different pesticide programs affect both the pests, non-target pests, and natural enemies. We currently have a grant that will develop these models into a training module for consultants, but we hope to provide feedback on WSU DAS to show the effects of different options on the overall complex of pests and natural enemies.

The San Jose scale model will be a fairly minor change in our current management programs (mainly moving treatments slightly later in the season), but it should give better timing for the first crawler generation and open a window for rescue treatments in the second generation. We will incorporate these timings in DAS during the next season.