BIOAg Project Report

Report Type: Final

Title: Using alternative host plants to improve accuracy of forecasting models for pest aphids

Principal Investigator(s) and Cooperator(s):

David Crowder (Principal Investigator). Crowder is an Associate Professor in the Department of the Entomology. As the PI he coordinated the project and mentored MS student Blance.

Robert Clark (co-PI, Postdoctoral Fellow). As a postdoc on the project Clark coordinated field surveys and developed statistical analyses (outbreak models); he also led the writing of the USDA NIFA grant.

Megan Blance (MS student, Entomology). Blance worked with Clark in the laboratory of Crowder to complete the project, which forms the basis of her MS thesis.

Ian Burke (collaborator). Burke is a Professor in Crop and Soil Sciences. Our group communicated with Burke to better understand the dynamics of weedy plant species in the Pacific Northwest.

Eric Roalson (collaborator). Burke is a Professor in the School of Biological Sciences. Roalson aided our group identify weed species collected as part of the project.

Abstract: Aphids are abundant, outbreaking insect herbivores that can deal considerable economic damage to cereals and legumes due to pathogens they transmit. While aphid-virus outbreaks can have catastrophic impacts on crops, we do not yet have reliable population models that predict the time and location for areas at high risk for aphid-virus outbreaks. Because these tools are not available, growers in the Palouse have resorted to intensive chemical control, treating all plants before outbreaks can occur to prevent yield losses. However, many insecticide applications are unnecessary as aphid outbreaks are intermittent, typically occurring only every 4-8 years. Aphid outbreaks are also typically isolated to certain subregions of the Palouse in any given year, and only growers in those subregions may need to use insecticides. In this project, we hope to dramatically reduce the reliance on chemical controls as a preventative measure by developing predictive models that can tell growers ahead of time if outbreaks are unlikely to occur. This new advancement is based on our past work that has identified early-season hosts that can harbor aphids an entire month before spring pea and summer wheat have sprouted. This suggests that if we can detect high (or low) levels of aphids in these alternative hosts, we can make predictions about risk to crops in each area. If successful, these models will be able to provide pulse and cereal growers with an "early warning" map of risk from aphids. To this end, our project has three goals:

(1) Identify which alternative host plants harbor outbreaking pea aphids and cereal aphids
(2) Develop predictive models for summer outbreaks based on early-season data
(3) Field-test these models to assess how large an area alternative hosts can predict outbreaks

This approach has been successful in potato crops for pests that spread pathogens. Our goal is that by providing more reliable information on aphid risk to growers, we can reduce the overall intensity of cereal-legume production and insecticide sprays in particular.

Project Description: Plant viruses have devastating consequences for many crops in Washington and worldwide, causing excess of $1B in annual damage. Most plant viruses are transmitted by insect vectors such as aphids, and vector control using insecticides is the primary tactic to prevent pathogens. However, many aphid vectors are generalists, and feed on both non-crop and crop hosts. Understanding the influence of non-crop hosts on the spread of pathogens is key, as vectors build up large populations on perennial non-crop hosts, which also are reservoirs for pathogens in crop landscapes. Indeed, aphids that vector many pathogens to cereal, legume, and potato crops in the Pacific Northwest accumulate on weedy host plants around field borders in spring and move into crops in summer when conditions are conducive. In 2018 and 2019, fieldwork by our lab in the Palouse identified two exotic weed species, vetch and clover, that are effective hosts for outbreaking aphids that emerge in non-cultivated areas up to a month before crop hosts emerge. In 2019, we observed exceptionally low abundance of aphids on these alternative hosts, and subsequently summer 2019 had some of the lowest aphid abundances on record. Similar results have been seen for psyllids and leafhoppers that transmit pathogens to potatoes, and our laboratory has used monitoring of these pests to produce "risk maps" for growers that are available through an online decision support tool and e-mail list serves (potatoes.decisionaid.systems). Data from across these systems suggest that monitoring non-host crops may provide a reliable indicator of potential risk to crops later in the year. Delivering information to growers on vector dynamics in non-host crops could help them make more proactive, and less reactive, management decisions.

In the Palouse region, legumes are critical rotational crops with cereals because they fix nitrogen, break disease and insect cycles and increase profitability. Cool-season food legumes (pea, lentil, chickpea) are also widely grown for human consumption, and Palouse growers produce nearly $80M in legume crops annually. There has also been incredible growth in production of winter peas, which can be sold in food distribution channels and can both intensify and diversity crop rotations in Washington. In the Palouse, pea aphids can transmit several devastating pathogens to legumes. Major outbreaks of pea aphids occur every 4 to 8 years, although aphids can be found in most legume fields every growing season. Past aphid outbreaks have led to devastating losses from viruses such as Pea enation mosaic virus (PEMV), which can reduce yields of legume crops by up to 40%. However, in many other years, aphids due almost no damage to legume crops and insecticide sprays are superfluous. Similarly, cereal aphid and bird-cherry oat aphids are widespread aphid species and vectors of Barley Yellow Dwarf Virus (BLRV). In the Palouse, BLRV has impacts on barley and wheat production but relatively little is known about the biology of the aphids in alternative hosts. There is evidence that aphids overwinter on weeds, such as clover and vetch, and the same is likely true for cereal aphids, but instead they are expected to be found on weedy grasses. Our overall goal in this project is to use information on aphid distribution from these weedy hosts to predict potential risk from aphid outbreaks in legume and cereal crops, allowing growers to make proactive decisions and reduce the intensity and frequency of insecticide sprays. This should increase grower profitability and sustainability without sacrificing crop yields.

Our project completed three objectives over the project period (2020 to 2021):

Objective 1 – Identify any further alternative host plants for pea aphids on weedy legumes and survey weedy grasses for cereal aphids in disturbed habitats adjacent to farms

Objective 2 – Develop predictive outbreak models using early season data for aphid abundance on weedy legumes and weedy grasses

Objective 3 – Test predictive models in subsequent field seasons to evaluate reliability and make tools available to growers online through WSU extension

Outputs

- Overview of Work Completed and in Progress:

Our project team completed surveys of aphids on weedy legume and cereal grass species in both 2020 and 2021. Our data in 2020 were particularly rich but in 2021 we only collected 400 aphids across our 20 field sites. From our field surveys we were able to document host use by pea aphids and various species of cereal aphids. These data have been incorporated into advanced statistical models that use data on aphid populations from early-season weedy hosts to predict populations in later-season crop fields. Preliminary models built by co-PI Clark showed that machine learning computer algorithms were able to predict aphid outbreaks in over 70% of fields surveyed, and we expect models to greatly improve as we collect data in future years. The BioAG project provided critical preliminary data that was leveraged in a USDA NIFA proposal that was awarded to Crowder and Clark for $710,000 in 2021. This project will allow us to expand the research and bring the decision support tools fully into the market.

- Methods, Results, and Discussion:

Figure 1. (A) Our surveys were conducted in weedy hosts along transects at the borders of crop fields and (B) using sentinel plants to draw in aphids

Objective 1 – Using an established sampling network of cooperating growers in Pullman-Moscow area, we surveyed 30 sites in 2020 and 32 in 2021. Using 10m transects, we quantified the weedy grass and weedy legume cover in each habitat, and then use sweep-netting, pan traps, and visual observations to sample for aphids. All aphids that were collected were tested for viruses using PCR. Our spring samples were conducted in habitats that were adjacent to crop fields and included roadsides, embankments, and low elevation habitats (canyons). An example of weedy hosts bordering a crop field is shown in the figure below (Fig. 1A). Our spring samples were paired with aphid collections at legume and cereal crop hosts during the summer months. We also tested a new methodology where we placed sentinel legume plants out in the field near weedy hosts to survey for aphids (Fig. 1B).

Our surveys of cereal aphids found five different aphid species, four of which are considered major pests, on over 50 potential host plant species. Total number of individuals of the following species were documented: *sitobion avenae, rhopalosiphum padi, metopolophium dirhodum, metopolophium festucae cerealium* and *sipha elegans*.

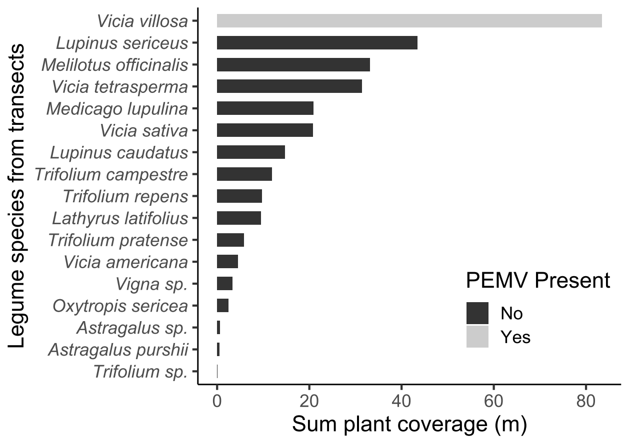

Figure 2. Abundance of legumes from most to least. Bar height indicates cover. PEMV was only found in one host, hairy vetch, which was also the most

We sampled a total of 62 agricultural and non-agricultural habitats for pea aphids from May 1 to July 15 across 2020 and 2021. In each site we completed transects on farm field edges and assessed coverage of each legume species. Using sweep nets, we then sampled each plant species for any aphids and *Pea enation mosaic virus* (PEMV). Hairy vetch was by far the most abundant non-crop host, covering 13.5% of all area (83.4 meters, Fig. 2). Hairy vetch was also the only non-crop host where we detected PEMV. Pea aphids were the dominant legume-feeding species (99.96% of aphids collected), with few bean (*Aphid fabae*) and lupine aphids (*Macrosiphum albifrons*) (these other species are not vectors of PEMV).

Across both of our study years, 44 sites had pea aphids on either pea or hairy vetch (Fig. 3A). Aphid abundance was typically low (<10), but exceptionally high at some sites (up to 12,000) (Fig 3A). Notably, high aphid densities were in several hairy vetch populations (Fig. 3A, black arrow), and PEMV was found in both hairy vetch and pea crops. This suggests: (i) hairy vetch sustains large populations of pea aphids and PEMV; (ii) PEMV in crops may be linked to vetch (Fig 3B); (iii) PEMV is patchy (Fig. 3A), such that other factors besides vector density are key for assessing pathogen movement across Palouse landscapes.

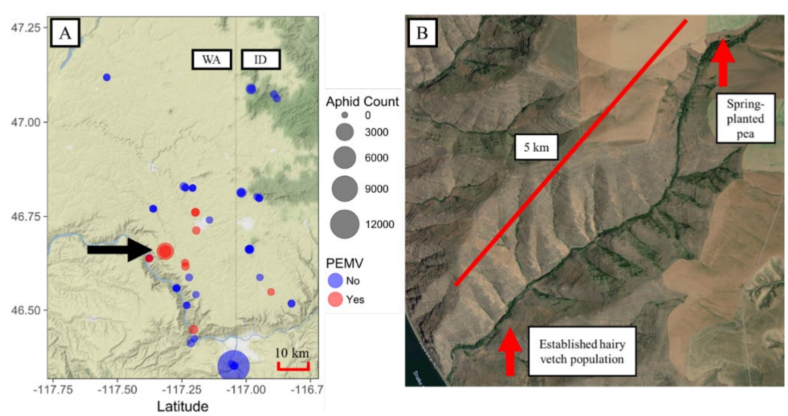

Figure 3. (A) Map of 2020 and 2021 surveys in managed and unmanaged habitats in the Palouse region (border of WA and ID). Dots are sampling locations, while a black arrow indicate two example aphid outbreaks of aphids. Circle size shows aphid abundance from sweep nets, and sites with PEMV are shown in red. (B) Example of a single paired location of vetch in an unmanaged habitat adjacent to cultivated pea fields.

Objective 2 – In Objective 1 we established a putative link between aphids in non-crop hosts and aphids in crops fields; in this objective, we assessed over how large an area these predictions might be accurate and how reliable they would be at preventing damage to crops (i.e., could aphid populations in non-host crops be used to forecast populations in crops later in the season). Using data collected from our observational sampling studies, we developed statistical models to determine which factors may be correlated with aphid outbreaks. These models included data on both cultivated and non-cultivated plants, aphid abundance in these patches, and abiotic factors such as temperature and precipitation. We predict that the larger (e.g., denser) patches of alternative hosts are more likely to harbor aphids, and that high early season density of aphids will be a strong predictor of aphid outbreaks in crops one to two months later in a > 2km radius given that aphids can travel long distances on wind and storm currents.

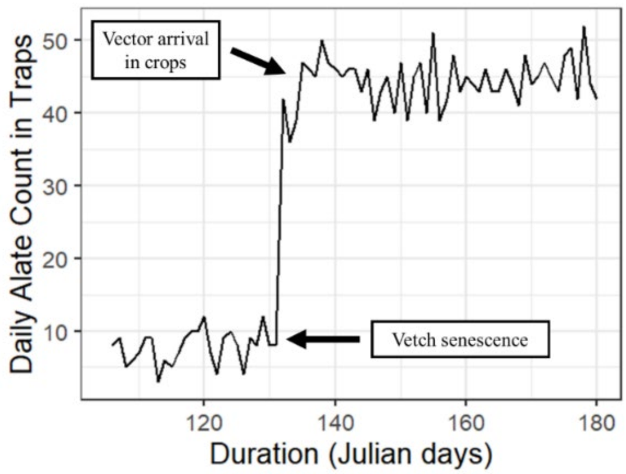

Figure 4. Time series model informed by aphid data in 2020 and 2021 field seasons. At approx. 130 Julian days, vetch begins senescence, and this is temporally linked with detection of alates within crop fields.

Co-PI Clark worked with MS student Blance to develop statistical models to predict outbreaks in crops based on populations in vetch. Aphids rely on a dispersal phase (alates) to move long distances, and when resources change, such as host plant senescence, or when aphids become highly abundant on host plants, aphid adults will detect these changes and begin to produce alates. Our preliminary work shows that alate formation starts abruptly in the field (Fig. 4), and this shift is correlated with hairy vetch life history as the dominant host in weedy plant populations. As a statistical tool, change point detection examines a time series dataset and reports intervals in which an underlying distribution of values change from one range of values to another and will allow us to predict data on aphids in the future (Fig. 4).

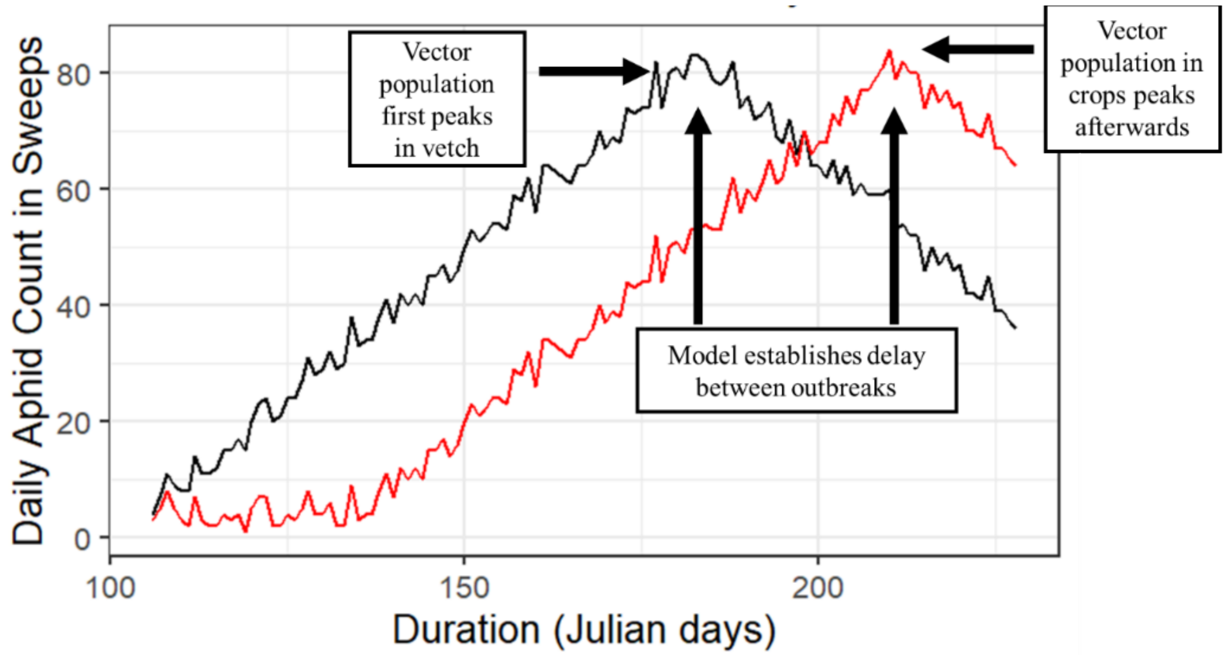

Figure 5. Cross correlation analysis of aphid vector outbreaks in vetch and pea populations. Variance is based on random Poisson values with λ of 8. This analysis simultaneously modelled vector abundance in vetch (back line) and pea (red line), and shows the time lag based on our sampling regime (lower black arrows), indicating how long it takes populations from vetch to be detected in pea.

Our work also suggests that outbreaks of aphids in legume crops may be synchronized with outbreaks of the same pest species in vetch. Using a temporally and spatially explicit framework, we built a model that tested whether the timing and intensity of outbreaks of aphid vectors in crops will track outbreaks in source vetch populations, with a relatively fixed time lag between the two events (Fig. 5). Our preliminary data from certain fields suggests this may be a viable approach in the future.

Objective 3 – Using our field and climate data, we developed a time series forecasting model to predict outbreak risk. We used an 'ensemble approach' where many models were developed and averaged; our approach will get stronger as we collect additional data. We identified two scenarios that commonly occur, including high and low infection risk (Fig. 6). In scenario A, the frequency of PEMV in traps climbs rapidly over 30 days, indicating that economic thresholds for damage are likely. In scenario B, the rate of change in the frequency of PEMV infection remains flat for 30 days, and the model predicts low risk of damage. We had evidence for both of these scenarios, but we need additional data to validate models.

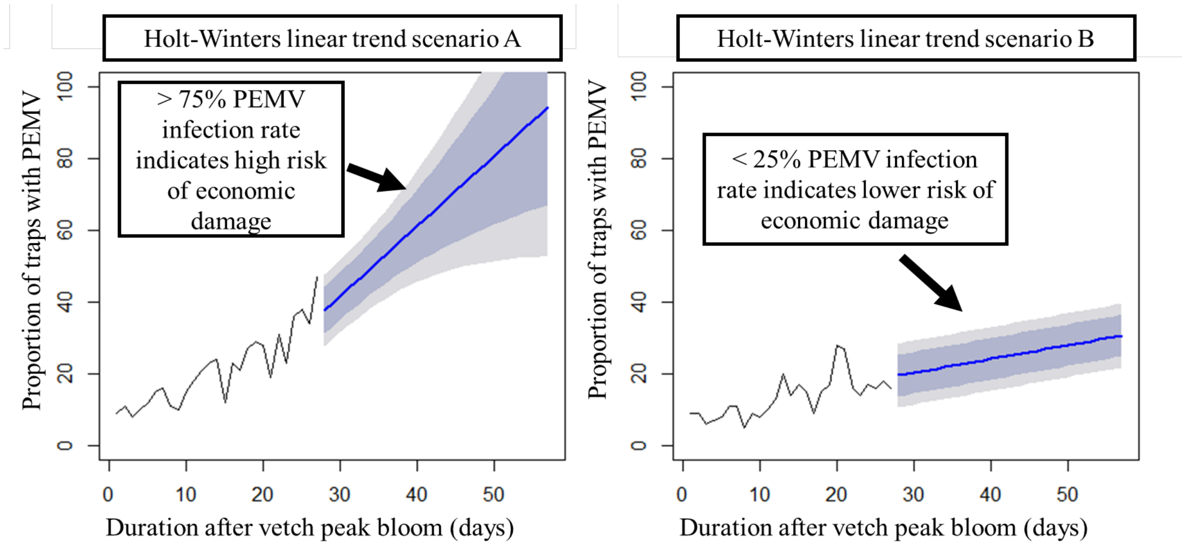

Figure 6. Early season data (30-day duration starting approx. April 15) demonstrating two simple forecast scenarios using Holt-winters linear trend method. Solid black line indicates hypothetical observed data, while blue, shaded line and area are predicted outcomes based on past observations.

Our team also created a mock-up of a potential tool we hope to host and deliver real-time information to growers (Fig. 7). This page will allow growers to obtain data from weather stations or gridded weather forecasts and predict when aphids will arrive in their fields (Fig. 7)

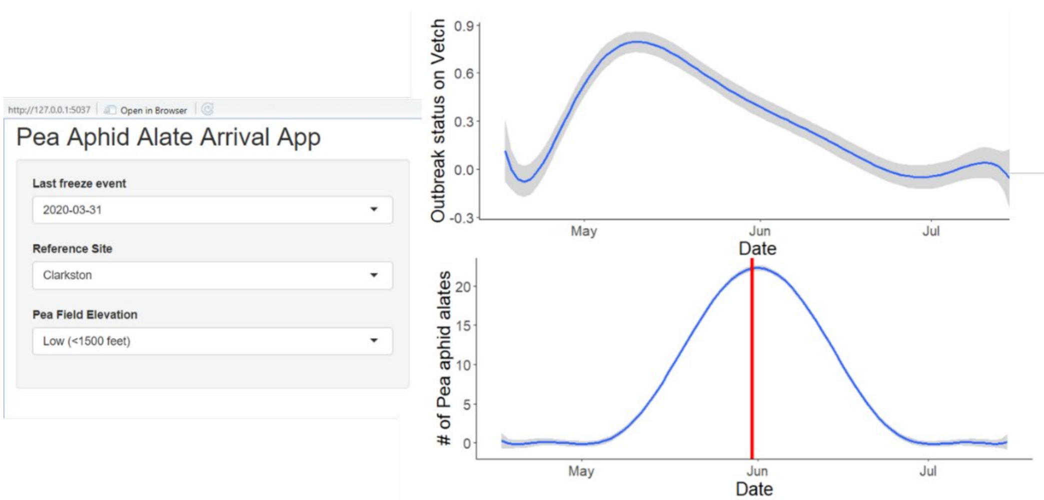

Figure 7. An example "Pea Aphid Alate Arrival App". The graph shows current conditions in vetch (upper panel) and then the predicted peak arrival in crops for the specific farm of the user (lower panel).

- Publications, Handouts, Other Text & Web Products:

Lee BW, Clark RE, Basu S, **Crowder DW** (2022) Predators affect a plant virus through direct and trait-mediated indirect effects on vectors.

Clark RE, **Crowder DW** (2021) Vector-borne plant pathogens modify top-down and bottom-up effects on insect herbivores. *Oecologia* 196, 1085-1093.

- Outreach & Education Activities:

Due to the COVID-19 pandemic our educational activities were curtailed from the original project, as we did not proceed with field days that had been planned. Crowder, Clark, and Blance all gave academic presentations at various conferences and departmental seminars in both 2020 and 2021

Impacts

- Short-Term:

(i) Detailed knowledge of host plant use by cereal and legume aphids
(ii) Detailed knowledge of migratory patterns of aphids into crop fields
(iii) Creation of preliminary predictive models for aphids

- Intermediate-Term:

(i) Increased use of digital tools by growers will aid them in saving money
(ii) Increased use of digital tools by growers will aid them in reducing insecticide sprays
(iii) Our team plans to produce forecasts of insect populations in real-time

- Long-Term:

(i) Increased use of digital tools by growers will aid them in saving money and reducing sprays
(ii) Developing of forecasting tools will improve pest management in other crops
(iii) Integration of models into WSU decision aid systems could provide millions in savings for growers. For example, in potato our forecasting models save growers $62/acre. Similar savings in other crops could produce tens of millions in reduced pesticide applications.

Additional funding applied for/secured:

We obtained a $710,000 USDA NIFA grant to extend the work and complete model validation

Graduate students funded: Megan Blance (MS Entomology, 2020-2021)

Recommendations for future research: Our USDA project will continue to build and validate models to predict aphid outbreaks in legume crops. We hope to extend the research more fully to cereal crops in the coming years. Forecasting models are also being developed in potato and other crops that may use methods developed in this project.