QUANTIFYING VINE MEALYBUG (*PLANOCOCCUS FICUS*) SPATIOTEMPORAL DYNAMICS: ASSESSING INVASION RISK TO REFINE MANAGEMENT STRATEGIES

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REPORTING PERIOD: The results reported here are from work conducted January 2018 to June 2018.

INTRODUCTION

Geospatial analyses and niche-based/species distribution modeling have previously been used to characterize plant, aquatic invertebrate, amphibian, and insect invasions. Results of these and similar investigations have been applied, with varying degrees of success, to develop early detection strategies, identify and prioritize management in high risk areas, and minimize monitoring expenditures (Bradley et al. 2010, Venette et al. 2010, Jiménez-Valverde et al. 2011, Vincente et al. 2016). An intriguing possibility is that information gained from geospatial analyses of invader spread and niche-based/species distribution modeling of suitable habitat for invaders may be used to simulate invader dispersal and predict invader distributions. Ensuing predictions of invader distributions could then guide detection and management efforts, as well as be evaluated and refined using field-collected data on invader occurrence. Here we use such tools to improve response to an important invasive insect in California vineyards, the vine mealybug (VMB; *Planococcus ficus* [Signoret]).

The vine mealybug is a severe vineyard pest that contaminates fruit, debilitates vines, and transmits plant pathogens such as *Grapevine leafroll-associated virus-3* (Daane et al. 2012; Almeida et al. 2013). Vine mealybug was first reported in California from vines in the Coachella Valley (Gill 1994) and soon spread throughout much of the state, likely on infested nursery stock (Haviland et al. 2005). It is currently found in most California grape-growing regions (Godfrey et al. 2002; Daane et al. 2004a, 2004b) and its range continues to expand. Despite the continued expansion of VMB distributions in California, its current distribution in Napa County and areas at risk of VMB introduction in this region are not well characterized.

Management of VMB has proven challenging and often requires the use of multiple tactics, including biological control, mating disruption, and insecticides (Daane et al. 2008). Management can be particularly complicated in coastal wine grape-growing regions where climatic conditions are favorable and Argentine ants (*Linepithema humile* [Mayr]) disrupt biological control (Daane et al. 2007, Gutierrez et al. 2008). Given that VMB may complete 3 to 10 generations per year under California climatic conditions, it has the capacity to develop large populations and is a serious risk of spread to new regions. Management costs may range from $300 to $500 per acre, per year for the life of the vineyard.

OBJECTIVES

Given the ongoing expansion of the vine mealybug (VMB; *Planococcus ficus*) in California and continued risk of its introduction into new areas, a better understanding is needed of what is driving its invasion. The overall goal of this research is to characterize the factors associated with VMB establishment and spread in Northern California vineyards, which will be addressed via the following objectives:

1) Quantify the spatiotemporal patterns in VMB occurrence to identify invasion hot spots and patterns of spread
2) Characterize the landscape, climatic, and anthropogenic factors associated with current VMB occurrence to predict areas at risk to invasion
3) Validate and update predictions of VMB risk via in-field monitoring

SUMMARY OF ACTIVITIES, ACCOMPLISHMENTS, AND RESULTS

Survey data on 2012-16 VMB occurrence were received from the Napa County Agricultural Commissioner's Office and cleaned (i.e., removal of duplicate records, identifying missing information, rectifying data inconsistencies, etc.). Traps in each trapping year were georeferenced relative to grid cells in the CDFA State Wide Grid System. Both the greatest number of traps recording captures and number of male VMB captured were recorded in 2016, but the number of male VMB caught varied considerably among trapping years (Table 1). A total of 4004 traps were deployed in 2016; VMB captures in this year appear to be highly clustered in grid cells located in the south-central region of Napa (Figure 1).

July 2018 Update: Our previous renewal report (February 2018) reported results pertaining to our 2012-16 VMB trapping records. We received 2017 VMB trapping data in March 2018; these records were cleaned and incorporated into our master dataset. We consequently repeated our Objective 1 analyses to reflect the inclusion of the 2017 trapping data. Including these 2017 VMB trapping records did little to alter the previously presented Objective 1 results. However, these 2017 data were accounted for in the Objective 2 results presented here. All final materials produced from this investigation (e.g., final reports and publications) will reflect the inclusion of the 2017 VMB trapping data.

Table 1. Summary of 2012-16 cumulative trapping effort for VMB in Napa County, California.

Year	# traps recording VMB captures	# male VMB captured
2012	577	49327
2013	327	16488
2014	296	43444
2015	841	26577
2016	1415	49785
2017	1602	55723

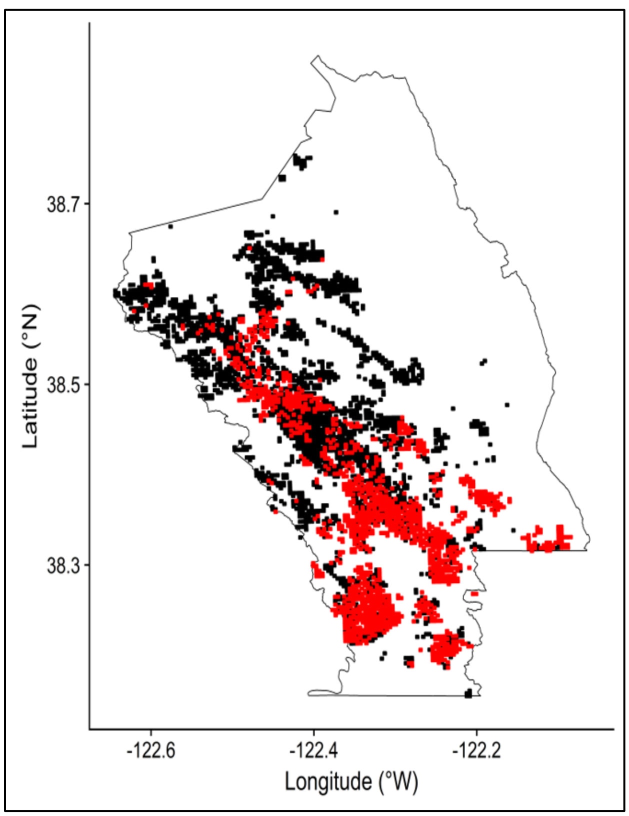

Figure 1. 2017 trapping effort for VMB in Napa County, with red cells denoting locations where VMB was detected and black cells denoting where traps did not detect VMB.

Objective 1
The inclusion of 2017 VMB trapping data necessitated we re-run geospatial analyses of spatiotemporal trends in VMB occurrence. More specifically, for 2012-17 VMB trapping records we evaluated the strength of spatial autocorrelation (SAC) among traps recording VMB captures, identified hotspots of VMB occurrence, and quantified both the directionality and rate of VMB spread in Napa for each study year.

Including the 2017 VMB trapping records did little to alter the previously presented Objective 1 results. We found that 2017 hotspots of VMB occurrence continued to increase in number and encompass hotspots previously identified using 2012-16 trapping records.

Objective 2
Analyses characterizing the landscape, climatic, and anthropogenic factors associated with current VMB occurrence and predicting areas at risk to invasion are complete. All 2012-17 records of VMB presence and absence were compiled by considering unique traps that recorded VMB detections in at least one study year (presence, n = 2208) or were deployed in at least one year but never recorded a VMB detection (absence, n = 2318). Variables of interest include 19 climate variables (WorldClim layers), elevation, percent impervious surface, and trap distance to nearest road and nearest winery. We also employed spatial eigenvector filtering to generate spatial predictors that reduce the signature of spatial autocorrelation among our presence-absence data. Our VMB presence-absence data and climatic, environmental, and anthropogenic predictors were used in conjunction with generalized linear models and Akaike's Information Criterion (AIC) to identify which spatial predictor variables to include in a final model predicting VMB occurrence. The final, AIC-informed model was used in conjunction with generalized linear models, boosted regression trees, and random forest algorithms to assess the relative importance of each predictor variable, quantify the magnitude and directionality of each predictor-VMB relationship, and generate predictions of habitat suitability for VMB in Napa County.

All modeling and ensemble methods employed to predict habitat suitability for VMB in Napa County performed well (Table 3; all ROC values > 0.8 and TSS values > 0.6). The boosted regression tree and random forest algorithm methods slightly outperformed the generalized linear modeling method. The grand ensemble method was the best-performing method employed (ROC = 0.953, TSS = 0.753).

Table 3. Performance of generalized linear model (GLM), random forest algorithm (RF), boosted regression tree (BRT), and a grand ensemble methods of predicting habitat suitability for VMB in Napa County, California

	GLM	RF	BRT	Grand
TSS	0.645	0.664	0.698	0.753
ROC	0.913	0.921	0.936	0.953

The relative importance of our selected anthropogenic, climatic, and environmental predictor variables varied among the modeling and ensemble methods employed (Figure 2). In general, the amount of precipitation in the driest month, elevation, and trap distance to nearest winery were identified as the most important predictors of VMB occurrence. Conversely, trap distance to nearest road was the least important predictor across all modeling and ensemble methods and exerted little effect on the probability of VMB occurrence.

Objective 3
The researchers working on this VMB project are devising plans to begin work on Objective 3. We are in the process of selecting sites and identifying grape growers and vineyard managers with which to coordinate in-field monitoring for VMB presence. This work will be conducted at a collection of sites representing gradients in predicted habitat suitability and distance from previous VMB detections. Ultimately, this work on Objective 3 will leverage the results of Objectives 1 and 2 to evaluate the accuracy of predictions of habitat suitability and risk of VMB infestation.

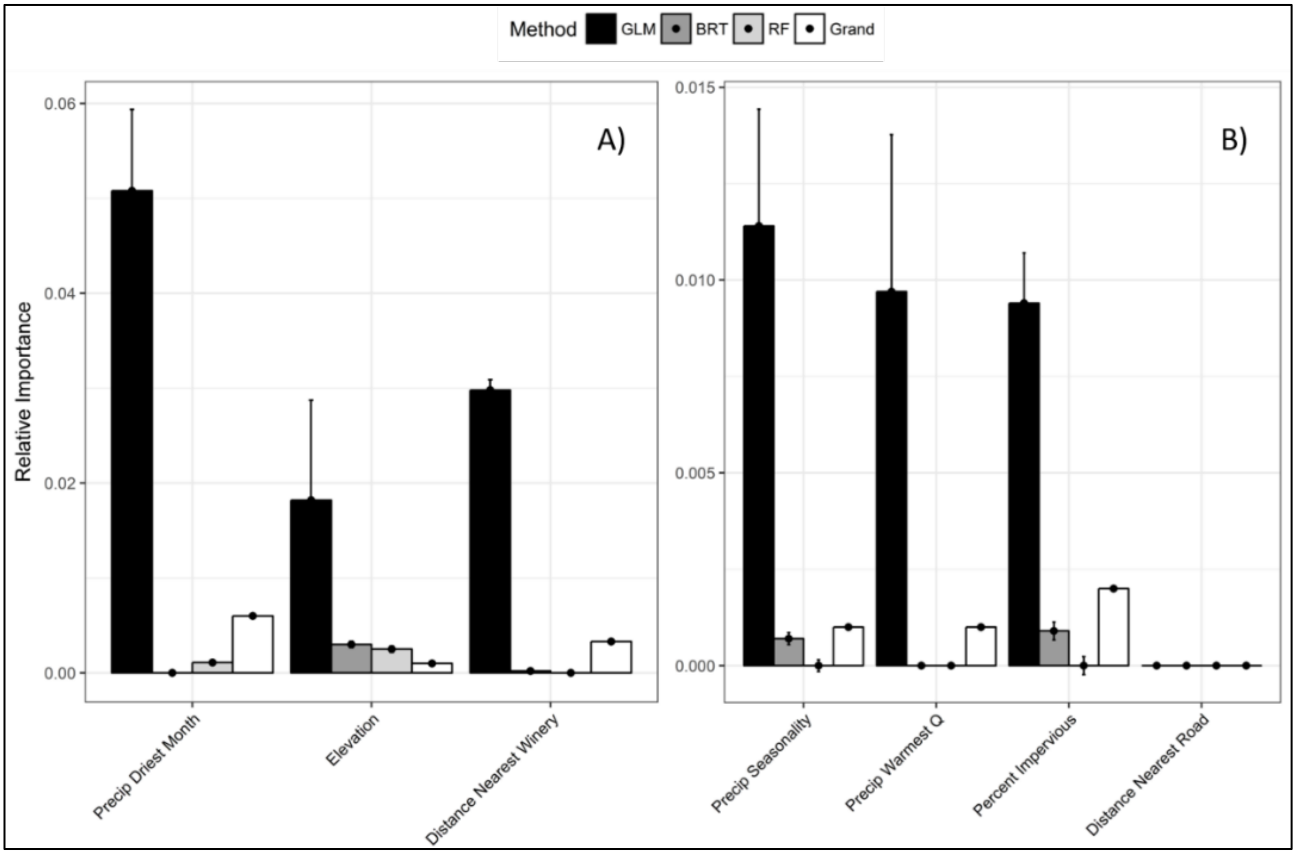

Figure 2. The relative importance of our selected climatic, environmental, and anthropogenic predictor variables when predicting habitat suitability for VMB in Napa County. Note the different y-axis scale between panels.

PROJECT PUBLICATIONS AND PRESENTATIONS

Select details on the project activities have been presented as a part of extension presentations by PI Daugherty to grapegrowers in the Central Coast and Southern California. Results from the project were presented to Napa Valley grapegrowers on March 7th, 2018 to update them on what has been learned about VMB invasion in the region. A publication detailing results based on 2012-17 VMB trapping data is in preparation and will be submitted for peer-review and publication in the near future. Results of this investigation will be presented November 11-14th at the annual Entomological Society of America meeting in Vancouver, BC, Canada.

RESEARCH RELEVANCE STATEMENT

Better understanding of the factors driving VMB invasion is needed to curtail its ongoing range expansion in California, continued risk of introduction into novel regions of the US, and expense of management efforts. For this research project, survey data on 2012-17 VMB occurrence is being used to quantify spatiotemporal patterns in VMB occurrence, identify factors underlying hot spots of VMB occurrence/activity, characterize factors associated with VMB establishment, and clarify pathways that contribute to VMB spread in Napa County, California. This work helps to explain infestation patterns of this pest and identify areas at risk of infestation in the future. An improved understanding of the directionality and rate of VMB spread, as well as the pathways by which this insect disperses naturally or is moved by human activity, may also inform regulatory steps and direct educational efforts toward mitigating spread by targeted risk reduction strategies. Ultimately, such information is critical for developing a statewide response to this important vineyard pest.

LAYPERSON SUMMARY OF PROJECT ACCOMPLISHMENTS

Data cleaning of 2012-17 VMB trapping efforts has been completed and these data have been summarized. We have redone our Objective 1 analyses to reflect the inclusion of 2017 VMB trapping data and concluded Objective 1 - analyzing spatial and temporal patterns of VMB occurrence/abundance. More specifically, we have evaluated the scale of similarity

(SAC) among traps recording VMB captures, identified locations where VMB occurs more frequently than by chance (hotspots), and quantified both the directionality and yearly rate of VMB spread for each study year. Including 2017 data did not alter previously reported results.

We have also concluded Objective 2 analyses using the full 2012-17 VMB trapping dataset. These results, especially the strength of SAC and directionality/rate of VMB spread, are essential to informing our ongoing analyses of what explains why certain locations appear to be more prone to heavy VMB infestations relative to other locations (Objective 2).

STATUS OF FUNDS

Thus far, the bulk of the project expenses have been associated with salary and benefits for a postdoctoral researcher. Over the recent project period, that researcher completed Objectives 1 and 2, and is currently working on Objective 3.

SUMMARY AND STATUS OF INTELLECTUAL PROPERTY ASSOCIATED WITH THE PROJECT

No intellectual property is anticipated associated with the project.

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