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

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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 (Thuiller et al. 2005, 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 are being 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).

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

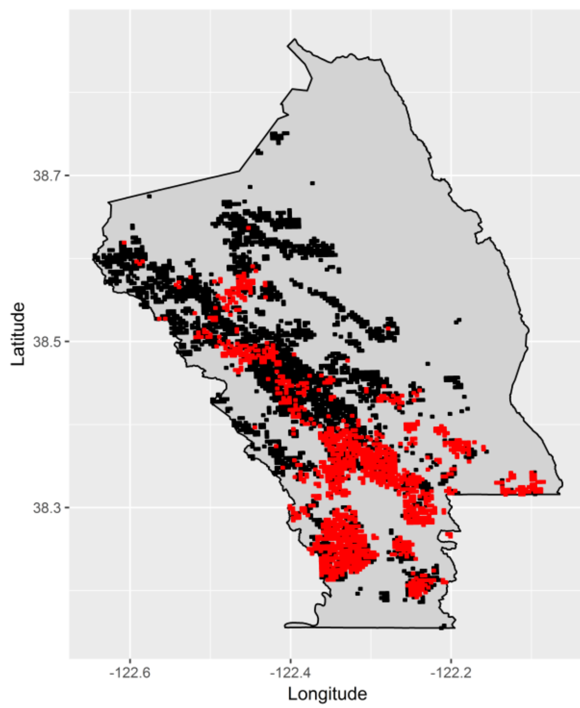

Figure 1. 2016 trapping effort for VMB in Napa County, with red cells denoting locations where VMB was detected and black cells denoting where traps did not detect VMB.

Objective 1

Analyses of spatiotemporal trends in VMB occurrence in 2012-16 are complete. More specifically, 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 County for each study year.

The strength of SAC among traps recording VMB captures was analyzed by aggregating all traps recording VMB captures (located in sub-grid cells) within CDFA trapping grid cells. Pair correlative functions were then used to estimate the strength of SAC for each study year; larger values indicate stronger SAC. In all years, SAC was greatest at the distance between traps (~250m). This trend in the spatial scale and strength of SAC is attributable to the regular spacing between traps in each year, and because of this regular spacing, we are unable to quantify SAC at finer spatial scales. However, the strength of SAC varied across study years; SAC was greatest in 2013 and weakest in 2016 (Figure 2).

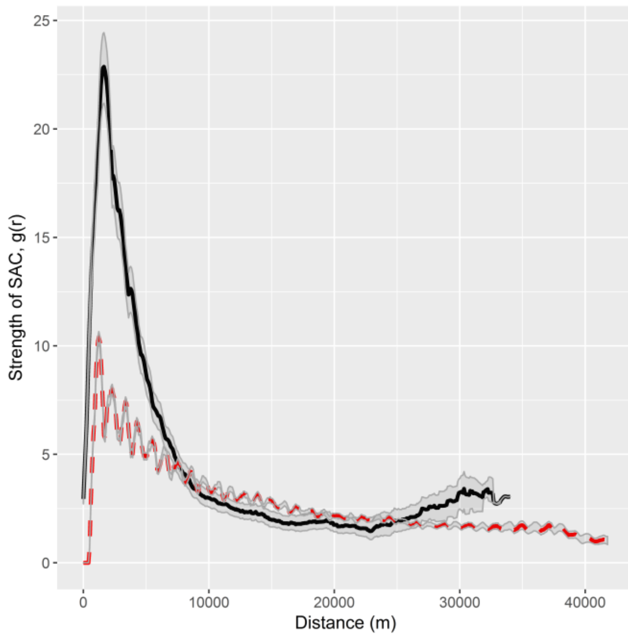

Figure 2. Estimates of the strength of spatial autocorrelation (SAC) as a function of distance among traps recording VMB captures in Napa. The strength of SAC was greatest in 2013 (solid black line) and weakest in 2016 (dashed red line). Grey shaded areas around each estimate represent 95% confidence intervals.

Hotspots of VMB occurrence are areas where a statistically greater numbers of traps recorded VMB captures relative to the rest of Napa County. Hotspots were identified by aggregating all traps recording VMB captures (located in sub-grid cells) in each year within CDFA trapping grid cells. A Getis-Ord statistic was then used to compare the total number of traps recording captures in each grid cell to all other grid cells within Napa County. Hotspots of VMB occurrence were identified in each study year (Figure 3). The location of some hotspots were consistent between study years.

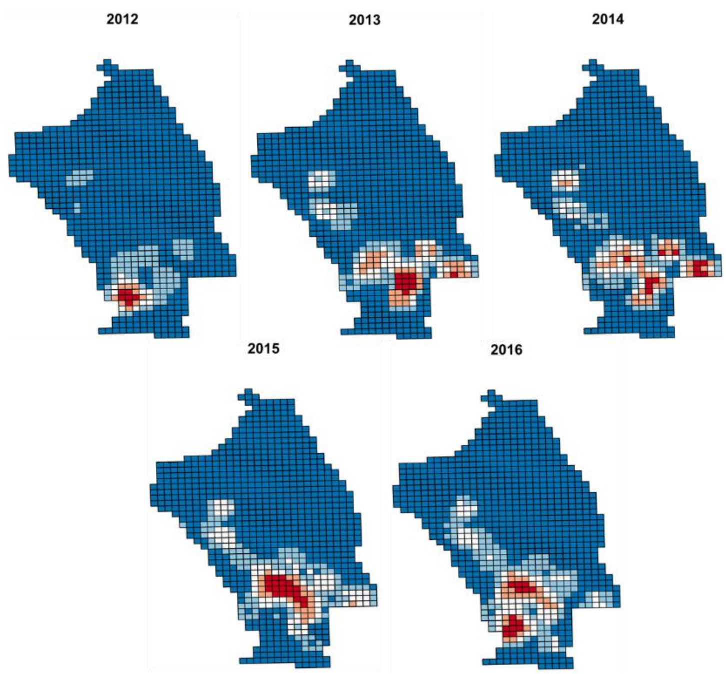

Figure 3. Hotspots (dark red) of VMB occurrence in Napa County in 2012-16. Hotspots are $1km^2$ grid cells that contain a statistically greater number of traps recording VMB captures relative to other grid cells throughout Napa County.

The rate of yearly VMB spread was quantified via distance regression, square-root area regression, and boundary displacement methods (Tobin et al. 2015). For each method, traps recording VMB captures in each year were subset by three different thresholds (presence-only, 10 and 100 VMB) in order to evaluate VMB spread relative to VMB abundances. Mean estimates of yearly VMB spread, and their associated errors, varied substantially among the three methods used (Table 2). The distance regression and boundary displacement methods produced the most conservative and liberal estimates, respectively, of VMB spread.

Table 2. Mean estimates, and associated standard errors, of VMB spread in 2012-16 generated via distance regression, square-root area regression, and boundary displacement methods. All estimates and errors are in meters.

	Distance		Square-root area		Boundary displacement	
Threshold	Mean	Error	Mean	Error	Mean	Error
Presence-only	348.9	34.4	691.2	391.2	838.2	50.0
10	228.3	47.4	457.8	336.5	587.4	43.1
100	119.6	115.4	128.3	155.2	693.9	75.2

The boundary displacement method also was used to quantify the directionality of VMB spread in each study year. Once again, traps recording VMB captures in each year were subset by three different thresholds (presence-only, 10 and 100 VMB) in order to evaluate directionality in VMB spread relative to VMB abundances. In general, there was considerable variation in the magnitude and directionality of VMB spread within and between study years (Figure 4), as well as the imposed thresholds of VMB abundances.

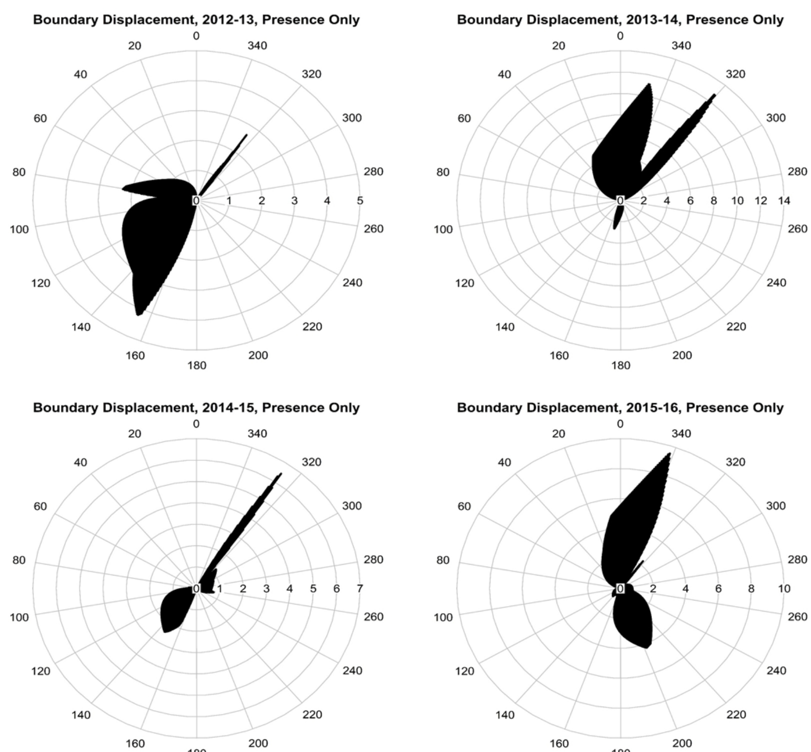

Figure 4. Example plots visualizing the magnitude and directionality of yearly VMB spread as estimated by boundary displacement methods. A presence-only VMB threshold was implemented when generating these figures. Displacement distances (i.e. concentric circles) are represented in hundreds of meters.

Objective 2

Analyses characterizing the landscape, climatic, and anthropogenic factors associated with current VMB occurrence and predicting areas at risk to invasion are ongoing. Variables of interest include 19 climate variables (WorldClim layers), elevation, percent impervious surface, distance to nearest road, and distance to nearest winery. Generalized linear models and information criterion methods (i.e., Akaike's Information Criterion, AIC) are being used to both identify which of the aforementioned variables are associated with VMB occurrence and quantify these relationships. Understanding of which factors are associated with VMB occurrence will then be used, in conjunction with multiple modeling methods (e.g., generalized linear models, boosted regression trees, and random forest algorithms), to generate predictions of habitat suitability for VMB and risk of invasion throughout Napa County.

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 will be featured in a planned presentation to Napa Valley grapegrowers in Spring 2018 to update them on what is being learned about VMB invasion in the region. At this point no publications have been produced based on project activities.

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 2012-16 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 2012-16 VMB trapping efforts has been completed and these data have been summarized. We have also 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. 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. That researcher has been hired and is actively working on Objectives 1 and 2. It is anticipated that the remainder of the funds will be expended on the same timeline as originally envisioned.

SUMMARY AND STATUS OF INTELLECTUAL PROPERTY ASSOCIATED WITH THE PROJECT

No intellectual property is anticipated associated with the project.

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