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Has Climate Contributed to a Pierce's Disease Resurgence in North Coast Vineyards?

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CLIMATIC CONDITIONS PLAY AN important role in agroecosystems via direct effects on plant performance and indirectly by influencing pest or pathogen dynamics[3]. Differences in temperature, precipitation or humidity may contribute to interannual variability in crop yield, quality, or damage and underlie long-term trends in such effects over longer timescales[12,19].

For grapevines, vine growth and berry quality are sensitive to climatic conditions, with the expectation that climate change is altering which regions are most suitable for premium winegrape production[21]. Climate change may also impact damage to vines, requiring changes to pest and disease management programs[5]. One disease whose epidemiology is strongly tied to climate is Pierce's disease (PD)[16].

Pierce's Disease and the Role of Climate

PD is caused by a strain of the bacterium *Xylella fastidiosa* that causes progressive leaf scorch, desiccation of fruit, defoliation, and vine death (FIGURE 1)[20]. Although there are some differences in symptom expression among cultivars[15], all conventional cultivars of *Vitis vinifera* are considered susceptible to the pathogen. *X. fastidiosa* is transmitted by multiple species of xylem-sap feeding insects, including sharpshooter leafhoppers and spittlebugs[20].

In coastal areas of California, PD is strongly associated with the activity by the native blue-green sharpshooter (BGSS, *Graphocephala atropunctata*), which is efficient at transmitting *X. fastidiosa* to grapevines[13]. Patterns of disease reflect proximity to BGSS reproductive habitats, with clustering of diseased vines typically on the periphery of vineyards near riparian habitats[13].

MATT DAUGHERTY

FIGURE 1. Grapevine in late summer showing characteristic leaf scorch symptoms of Pierce's disease.

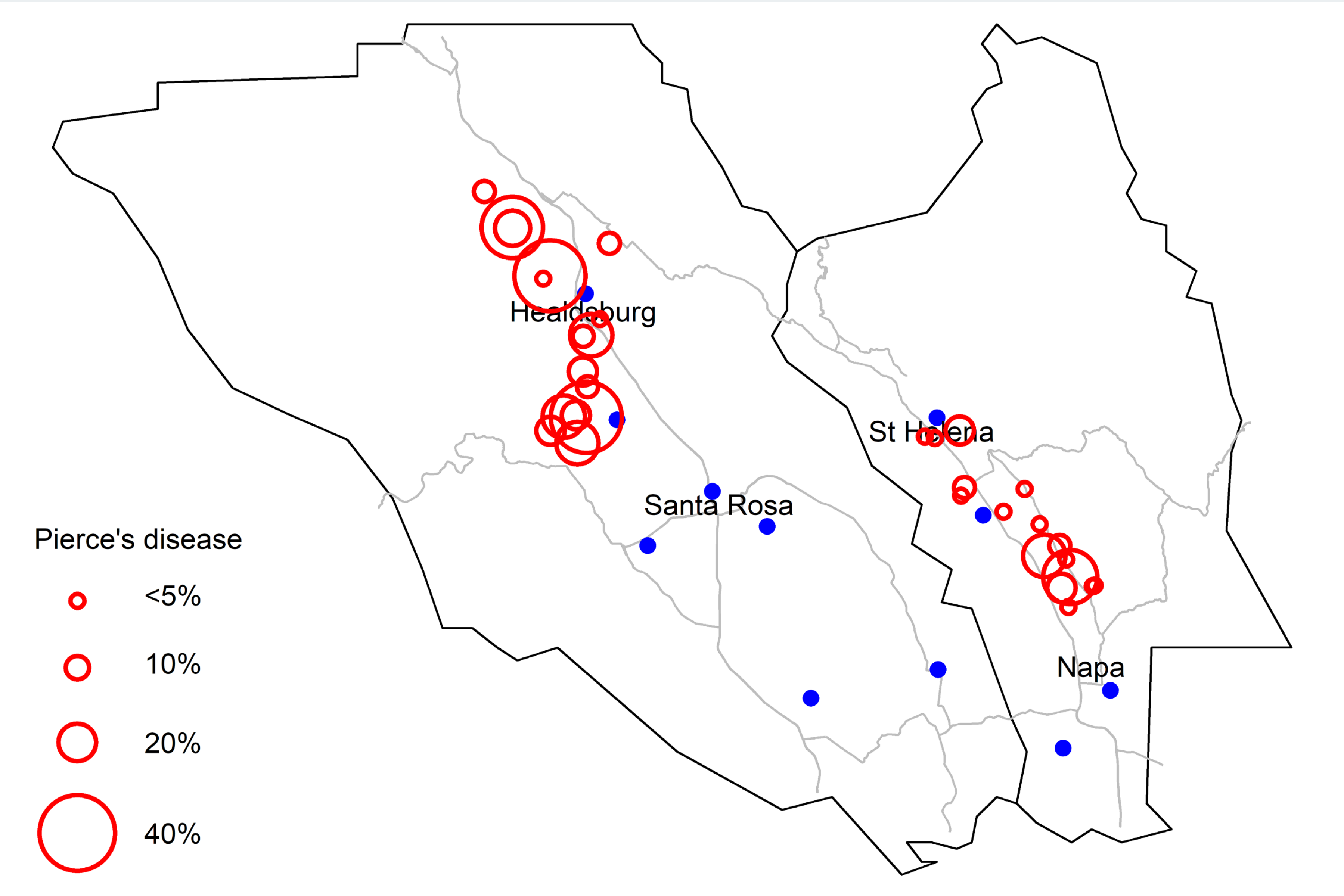

FIGURE 2. Map of the study region, including Sonoma and Napa counties. Open symbols denote the prevalence of Pierce's disease (i.e. percent of infected vines in Fall 2018) at 32 vineyards surveyed as part of other research, some of which have upwards of 30 percent of vines infected. Blue points denote the location of 11 weather stations used in analyses, and gray lines show major roads.

PD in the North Coast, including Napa and Sonoma counties, is episodic—modest in most years, but with occasional periods of high incidence. At least three epidemics have occurred in the region since the 1970s, including an ongoing resurgence in which surveys have documented upwards of 30 percent disease in some vineyards (FIGURE 2)[1]. A comprehensive understanding of the episodic nature of PD in this region, or the cause of the current outbreak, is lacking. Ongoing research by the authors, funded by the Pierce's Disease Control Program (*cdfa.ca.gov/pdcp/*), is evaluating the potential drivers of this resurgence, including whether recent climatic conditions played a role[1].

PD epidemiology has been known to depend on climate for several decades, based on observations that disease incidence was higher following high rainfall years[22]. Many aspects of the PD pathosystem have been linked to temperature or precipitation. In the field, BGSS densities are higher following warm, wet rainy seasons[10], and temperature influences seasonal patterns of BGSS reproductive and flight activity[4].

Experiments confirm that most aspects of sharpshooter performance are strongly related to temperature, including higher feeding rate[18], development[2], overwinter survival[17] and transmission of *X. fastidiosa*[7] at higher temperatures. In addition, *X. fastidiosa* infections depend on climate, particularly temperature. The multiplication rate of *X. fastidiosa* is generally positively related to temperature[9], which results in plants becoming a source of infection sooner and a more rapid disease onset under warmer conditions[8].

Temperature influences the percentage of vines that lose infection over the winter, with more recovery under colder conditions or at locations with more frequent cold winter days[9,11]. Such effects likely explain why PD appears to be restricted to certain coastal and southern areas of the United States[14]. They also suggest that interannual or longer-term differences in climate may be epidemiologically significant, with disease incidence expected to be highest around relatively wet, warm rainy seasons and warm growing seasons.

Here, we ask whether recent climatic conditions in the North Coast have contributed to the ongoing PD resurgence by using long-term weather station records. Specifically, multiple temperature and associated metrics were analyzed to determine if conditions surrounding the approximate onset of an outbreak were noticeably different than historic observations in a way that is expected to favor PD.

Best Practices for Sharpshooter and Pierce's disease Monitoring

Monitoring is needed to guide when or where vector management should occur. The easiest way to monitor blue-green sharpshooter is with double-sided sticky traps, which are available from several retailers (FIGURE 3). Vary trap number based on block size, from at least a few traps for small blocks (less than two acres), up to one per two to three acres for larger blocks. Spread traps along the periphery of the block, especially nearby vector sources (riparian habitat, ornamental plantings) or other areas with high PD prevalence in the past. Place traps on trellis wires or posts above the trellis, slightly above the canopy, raising them as the canopy develops. Check traps at least monthly from budbreak through leaf fall, particularly during the Spring when weekly to biweekly checks may be justified. Record the number of sharpshooters and replace the trap as needed.

Disease surveys should occur yearly to identify which vines to remove due to lack of vigor or limit sources of infection for vectors. PD symptoms are most apparent later in the growing season. Visually inspect each vine in the late Summer or early Fall, and flag those vines with symptoms for later removal. PD can be highly variable, and may appear similar to other diseases (Esca, Grapevine Leafroll Disease), nutrient deficiencies (magnesium, potassium), and excess soil salinity. Prior to vine removal, if unsure about symptoms, consider sending a sample of one leaf per vine collected from a subset of suspected PD vines to a laboratory for confirmation.

2020 PD/GWSS REFERENDUM

California grape growers will vote in Spring 2020 on extending the Pierce's Disease and Glassy-Winged Sharpshooter (PD/GWSS) Assessment for another five years. The assessment funds research to find solutions to PD, GWSS and additional designated pests and diseases of winegrapes. Every entity that produced and sold winegrapes in 2019 will receive a ballot. Growers who operate multiple entities will receive a separate ballot for each entity; they are not duplications. Each ballot should be voted upon and returned.

CHRISTOPHER FREEZE

FIGURE 3. Double-sided yellow panel trap used in a vineyard to monitor for blue-green sharpshooter and other insects.

Key Points

- Pierce's disease (PD) has affected grape production for as long as commercial vineyards have been present in California.
- Ultimately a large-scale, long-term monitoring program is needed in the region to understand comprehensively the role of climate in triggering a PD outbreak.
- Several PD epidemics have occurred, but their causes have not always been clear.
- Since approximately 2012, vineyards in the North Coast of California have seen a marked increase in PD prevalence, at least the third such outbreak since the 1970s.
- Local climatic conditions are known to affect many aspects of the PD pathosystem, including performance of the pathogen (*Xylella fastidiosa*) and vector (*Graphocephala atropuncta*).
- Analyses were conducted to assess whether the climate in recent years may have contributed to the observed PD resurgence in the region.
- Observed higher temperatures during both the dormant and growing seasons are consistent with elevated PD incidence in some, but not all, recent years.

Analysis of Recent Climatic Conditions in the North Coast

Records were collected from 11 weather stations located throughout Napa and Sonoma counties (FIGURE 2) that are part of the California Irrigation Management Information System (CIMIS) or National Climate Data Center networks (*ipm.ucanr.edu/weather/index.html#weatherdata*). Each included up to 90 years of daily measures of minimum and maximum air temperature, which were used to analyze multiple temperature and associated metrics during two seasons: "dormant" (November to March) and "growing" (March to November). Patterns in precipitation were not explored given the historic drought in the region at the time, which if anything constrained PD incidence[10].

Three temperature metrics were considered for the dormant season: mean daily minimum temperature (°C), number of days with a minimum temperature less than 4°C (i.e. frequency of "cold days")[11] and maximum temperature. For the growing season, three similar metrics were considered: mean daily maximum temperature, number of days with maximum temperatures above 18°C (i.e. frequency of "warm days"), and the time to reach the degree-day requirement for *G. atropunctata* BGSS development (i.e. 162 degree days). This last metric reflects how quickly the offspring of overwintering adults develop to become active in vineyards the following summer, which was calculated starting in January following research from E.A. Boyd and M.S. Hoddle[4].

Prior to analysis, values of each metric were standardized yearly between 2011 and 2016, by dividing by the historic mean for each weather station through 2010. Values greater than 1.0 represent yearly observations that were warmer, more frequent, or slower than observed historically, whereas values less than 1.0 equate to observations that were colder, less frequent, or more rapid than was historically the case.

TABLE 1. Range in historic values among weather stations, and test for overall significant difference between recent years and historic averages (i.e. intercept ≠ 1), for temperature and associated metrics during the dormant or growing seasons. Results are from a set of linear mixed-effects models with a random effect of weather station[6].

		intercept			
	historic values	**x^2**	**df**	**P**	**value (se)[1]**
Dormant season (Nov-Mar)					
min. temp.	2.1 - 4.9°C	10.214	1	0.0014	0.959 (0.011)
cold days	60 - 98.3 d	13.264	1	0.0003	1.208 (0.043)
max. temp.	15.3 - 16.8°C	17.917	1	<0.0001	**1.029 (0.005)**
Growing season (Mar-Oct)					
max. temp.	23 - 28°C	1.068	1	0.3015	0.993 (0.007)
warm days	184 - 217 d	3.736	1	0.053	**1.023 (0.011)**
d-d requirement[2]	136 - 184 d	2.961	1	0.0853	1.045 (0.026)

[1] **bolded values** are consistent with effects expected to be associated with higher PD incidence.

[2] Number of days required to meet the degree day developmental requirement for blue green sharpshooter.

A set of statistical analyses were conducted to test, overall, whether the standardized temperatures and associated metrics in recent years differed from the historic average (i.e. 1.0)[6]. We then evaluated the following predictions for each year: warmer temperatures than was historically the case (i.e. more than 1.0), fewer cold days during the dormant season (i.e. less than 1.0), more warm days during the growing season (i.e. more than 1.0), and shorter times to reach the degree-day requirement (i.e. less than 1.0).

For the dormant season, historic means of the three climate metrics varied up to two-fold among the coldest and warmest sites, with minimum temperature showing the widest range (TABLE 1). The intercepts for all three metrics differed significantly from 1.0 (TABLE 1), and some years had significant deviations from historic means in a direction that may have contributed to PD incidence. The 2014-15 dormant season had higher minimum temperatures and lower frequency of cold days than historic averages, and both the 2013-14 and 2014-15 seasons had higher maximum temperatures (FIGURE 4).

For the growing season, mean values of the three climate metrics varied up to 35 percent among the coldest and warmest sites (TABLE 1). The frequency of warm days had an intercept that was marginally different from 1.0, whereas the other two were non-significant (TABLE 1). There were significant deviations from historic means for two of the metrics in a direction that is consistent with greater PD pressure—daily maximum temperature was higher in 2015 (FIGURE 5A) and the frequency of warm days was greater in three of the years (FIGURE 5B).

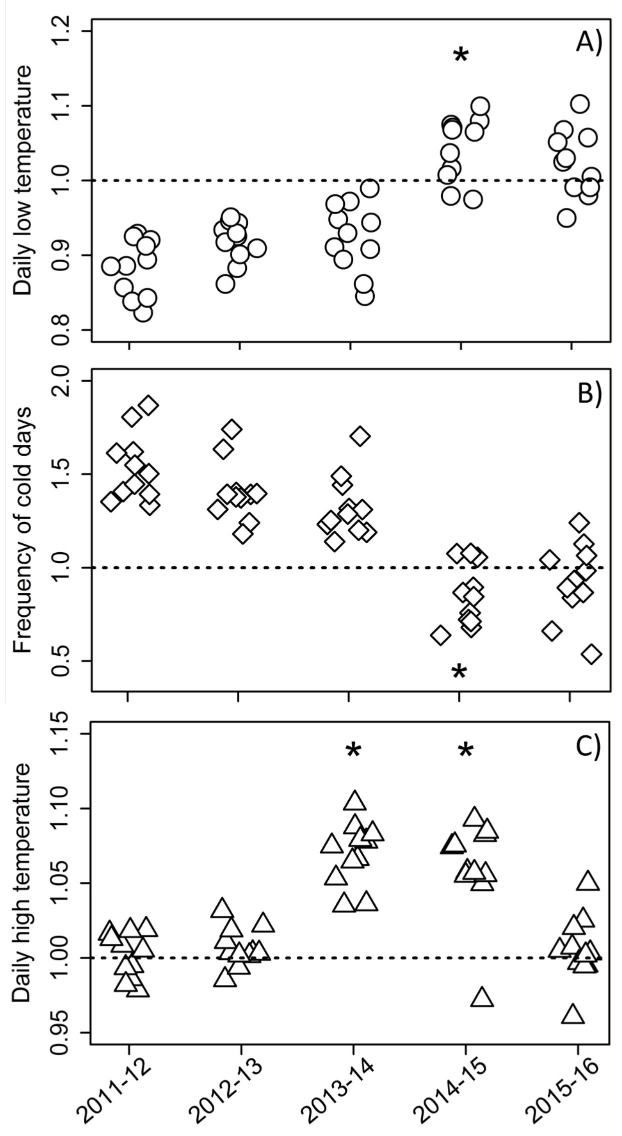

FIGURE 4. Relative A) daily minimum temperature, B) frequency of days with minimum temperatures below 4° C, and C) maximum temperature, November to March – 2011/12 to 2015/16.
"*" denotes seasons significantly warmer than historic means (dotted line).

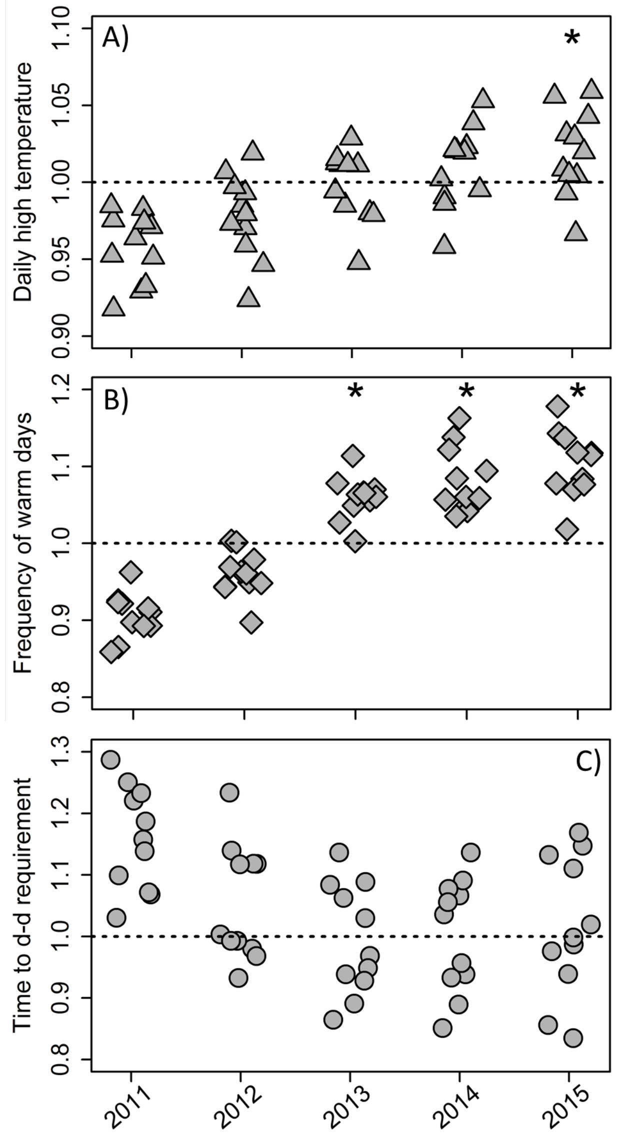

FIGURE 5. Relative A) daily maximum temperature, B) frequency of days above 13.3° C, and C) time to sharpshooter degree-day requirement, March to October – 2011 to 2015.
"*" denotes seasons significantly warmer than historic means (dotted line).

Conclusions and Next Steps

For vector-borne diseases, epidemics may be attributable to a wide range of factors associated with the pathogen, vector, host or environmental conditions. *X. fastidiosa* exemplifies this potential for multiple triggers of disease outbreaks[16], with periods of unusually high incidence that have been ascribed to pathogen introduction, prevalence of nearby reservoir hosts, invasion by a new vector, and with climate likely playing an important role[14].

Multiple lines of evidence indicate that warmer conditions are generally expected to increase sharpshooter populations or activity, and *X. fastidiosa* infection levels and persistence. Long-term datasets are lacking that would allow for explicit tests of the role of climate in presumed increases in vector or pathogen pressure building to outbreak conditions. As a preliminary step toward addressing this hypothesis, contemporary weather station data relative to historic values was compared to determine if they differ in a way that is expected to exacerbate PD incidence.

In the analyses presented, one metric each in the dormant and growing seasons had an overall intercept that differed significantly from historic conditions in a manner that is consistent with greater PD. Moreover, for five of the six metrics in at least one of the contemporary years, there was a significant deviation from historic averages that may favor higher vector populations and activity levels[10,18,] or more rapid development and greater persistence of infections[8,9,11]. Thus, it is plausible that these significantly warmer conditions in recent years elevated PD incidence in the North Coast[1].

Yet, the results were also mixed in that all temperature metrics were not significantly different from historic averages in all years. Indeed, by some metrics, the first couple of years (2011 and 2012) during this window of time appear colder than historic averages. Nor is it known definitely how many consecutive years of warmer than typical conditions are required to elevate the risk of a PD outbreak.

Ultimately, a comprehensive understanding of whether recent conditions contributed to the ongoing North Coast PD resurgence will require long-term, large-scale observations of sharpshooter abundance and *X. fastidiosa* infection dynamics in vines beyond what are currently available. Such information is needed to gain insight into the episodic nature of PD in the region, and to eventually be able to predict when an outbreak is likely to occur. In the absence of such predictive tools, it remains especially important for grape growers to monitor regularly for sharpshooters and PD (see sidebar), to identify those areas most at risk and to guide management decisions. WBM

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