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Briefing Paper: Recent changes in the ACP/HLB invasion in California and implications for regional quarantines

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State-wide background risk level for HLB

Since 2012, a background risk level for HLB in both residential and commercial citrus in each square mile of interest has been calculated 2-3 times per year using a risk model developed in Florida and adapted for use in California (Gottwald et al., 2014). The model uses a range of risk variables including census data, topography, land use, and known incidence of both HLB and Asian Citrus Psyllid (ACP) to produce a risk value ranging from 0 (extremely low risk) to 1 (very high risk) that applies to each square mile. Figure 1 shows the current risk status across the state at a county level, where the risk level applied to the county is the highest value for any individual square mile within that county

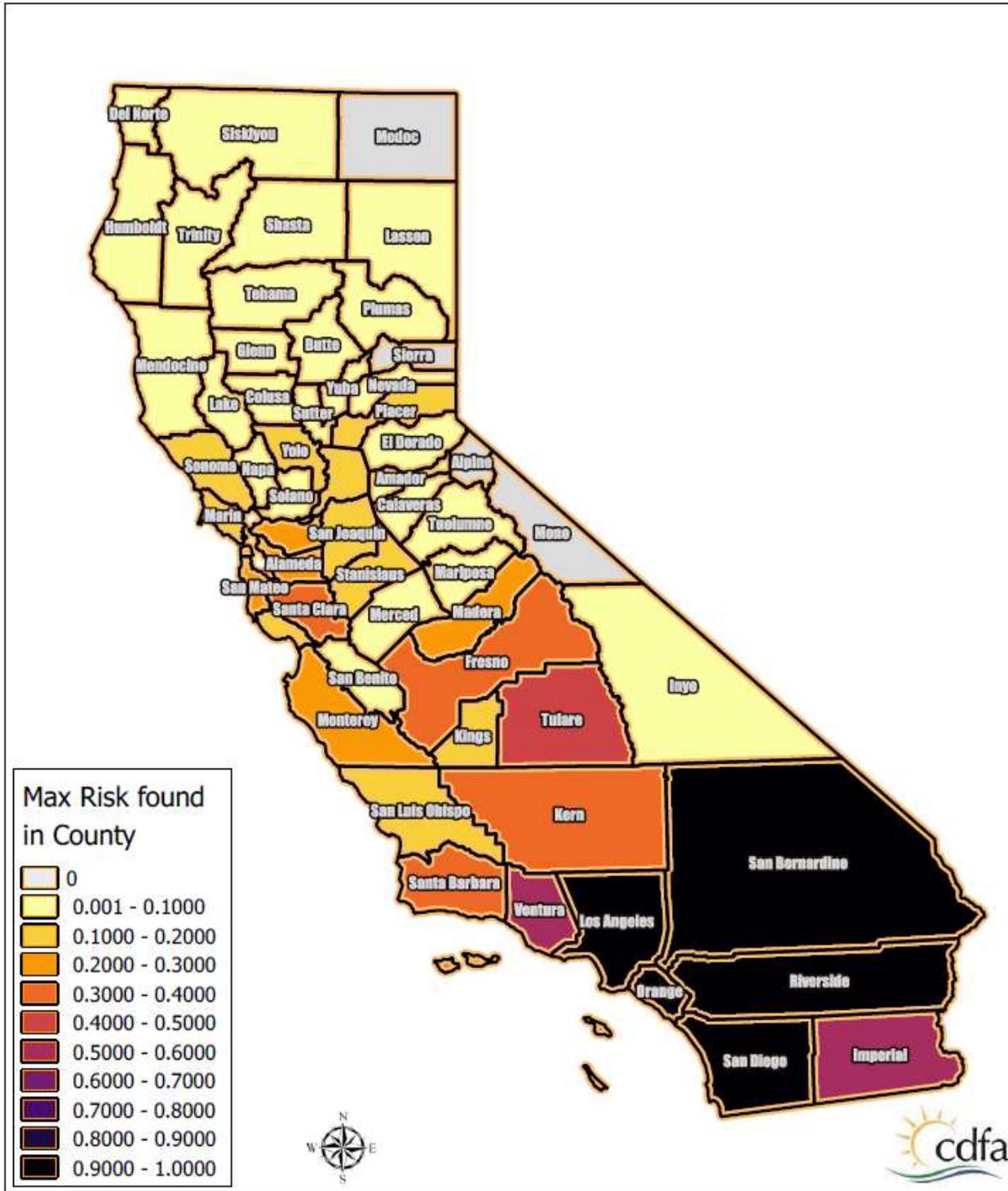


Figure 1. Maximum HLB risk level by county across California as estimated by the USDA-ARS HLB risk model.

In Figure 1 note that the risk level is generally higher in the south than north, because of the known presence of HLB and large ACP population in the southern counties. Note also that in northern California even counties with only a few ACP detections – for example Santa Clara County – may still have

relatively high risk levels because of population census data that indicate the background risk of the presence of infected citrus in private yards is relatively high. To illustrate this point further, Figure 2 shows the San Francisco Bay Area in more detail.

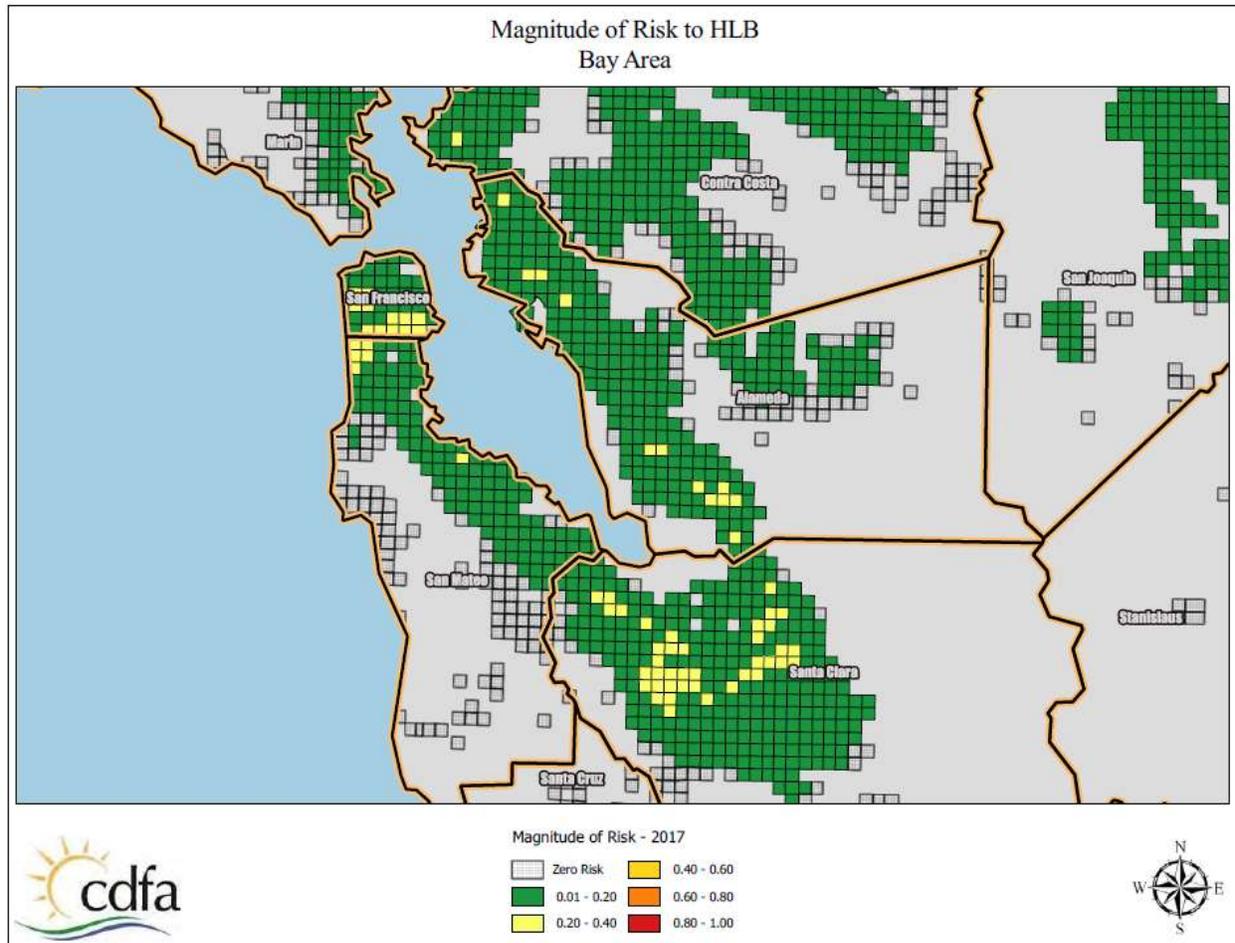


Figure 2. Individual square mile HLB risk levels for the San Francisco Bay Area. Note that the general risk level is low, but there are pockets of moderately high risk in San Francisco itself, and more noticeably in San Jose, associated with population census risk factors; ACP detections in this area is still low and sporadic.

While the background risk of HLB is strongly dependent on factors which are either static (e.g. topography) or change only slowly (e.g. human socio-economic factors) the presence of the ACP vector of the pathogen introduces a large dynamic component into the risk level across the state. To illustrate the impact of the vector population on changing risk status for HLB Figure 3 shows changes in HLB risk for the proposed quarantine areas 5 (San Diego, Imperial and Eastern Riverside) and 6 (LA, Western Riverside, San Bernardino and Orange). The risk level is shown as a blue-to-red heat map with higher risk indicated by darker red color and lower risk indicated by darker blue color; a time series of six periods is shown for each area.

Zone 6, 2012-13



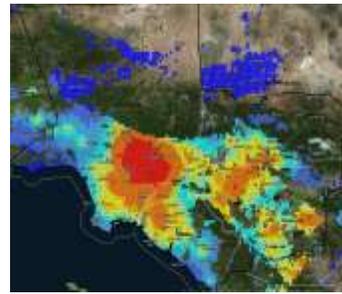
Zone 6, 2013-14



Zone 6, 2014-15



Zone 6, 2015-16



Zone 6, 2016-17



Zone 5, 2012-13



Zone 5, 2013-14



Zone 5, 2014-15



Zone 5, 2015-16



Zone 5, 2016-17



Figure 3. Changes in background risk of HLB in proposed quarantine areas 5 and 6 from 2012 to present. Red color indicates high risk, blue indicates low risk. Note that the location of the early HLB detections in Hacienda Heights and San Gabriel falls inside the single high-risk area predicted in 2012. The progressive increase in risk in both areas is apparent with the passage of time. All known cases of HLB are in proposed Quarantine Area 6.

Figure 3 tells us at least two useful things about HLB risk. First, note that in 2012-13 the only area of predicted high risk was centered on Hacienda Heights and San Gabriel, the locations of the first HLB discoveries in California; in other words, the risk model correctly anticipated the presence of HLB. Also note that the model also highlighted the focus of high risk in the city of Riverside as early as 2013-14; this outbreak emerged in 2017. These results are important for interpreting the presence of areas of elevated risk in places such as San Jose. Second, the pattern of change in risk in both areas 5 and 6 is a steady increase, spreading out from the original high risk area in LA, but also with additional foci developing at locations quite distant from the original focus. These changes are associated mainly with the spread of ACP through the region and the patterns of population density of the insect recorded in the risk-based surveys.

Taken together the results presented in this section highlight two important aspects of HLB risk that are relevant to quarantine regulations:

1. Because HLB-affected citrus plant material can be propagated and spread by human activity, the risk of HLB and ACP are to some extent independent, particularly in areas that are not generally infested with ACP.
2. **The risk of HLB can exist before the arrival of the vector** in an area because HLB-affected plant material is often brought to an area by human activities.

After ACP infests an area with pre-existing infected trees present, the vector population eventually comes into contact with the infected trees and foci of disease begin to build around them. This is because ACP acquires the pathogen from the infected trees and establishes a recurring cycle of infection and acquisition. Because trees remain asymptomatic for a long period of time, spread in the absence of detection and tree removal can occur.

Reducing disease spread by quarantines

The basic principle of underlying the use of quarantines is to restrict the spread of disease by sub-dividing an area into smaller regions and limiting the opportunities for disease to spread from one region to another. In the case of invasive and highly mobile diseases, quarantines should be applied early and rigorously to have the largest effect on disease spread. Importantly, quarantines do not have to be 100% effective to be worth imposing. If the incursion of the disease into generally uninfected areas can be limited to a low rate, and psyllid populations can be kept low, local eradications can be achieved when new incursions are detected.

The basic idea of setting up quarantine regions within the state is an ecological analogue of the idea of constructing a ship using multiple watertight compartments; even if one compartment is flooded, as long as the flow of water is negligible to the other compartments the ship won't sink. In instituting a quarantine policy, the aim is to limit the flow of vectors and disease throughout the state and thus safeguard the industry and homeowners as a whole.

Recent changes in the dynamics of HLB/ACP detections

Until recently, the rate of accumulation of new positive ACP and tree detections had been relatively stable. Over the last 6 months there has been a dramatic increase in the rate of new detections of HLB infections in both ACP and citrus trees. In addition, there has been a recent increase in the number of cities in which positive finds have been reported and a sharp increase in the number of ACP nymph detections. These results are summarized in Figures 4 through 7.

Taken together the results indicate an exponential increase in the intensity of the HLB epidemic at multiple scales. The pathogen is becoming more prevalent in the vector population and in the tree population. At the same time, the upswing in nymphal detections indicates that the transmission rate is increasing and the increase in the number of cities with positive detections indicates that the geographic extent of the epidemic is increasing rapidly.

Most of these changes have become apparent only in the last 6 months. Given the very sharp increase in the intensity of the epidemic, a rapid response is needed to implement additional measures to slow the rate of spread of HLB beyond its current range before the opportunity is lost.

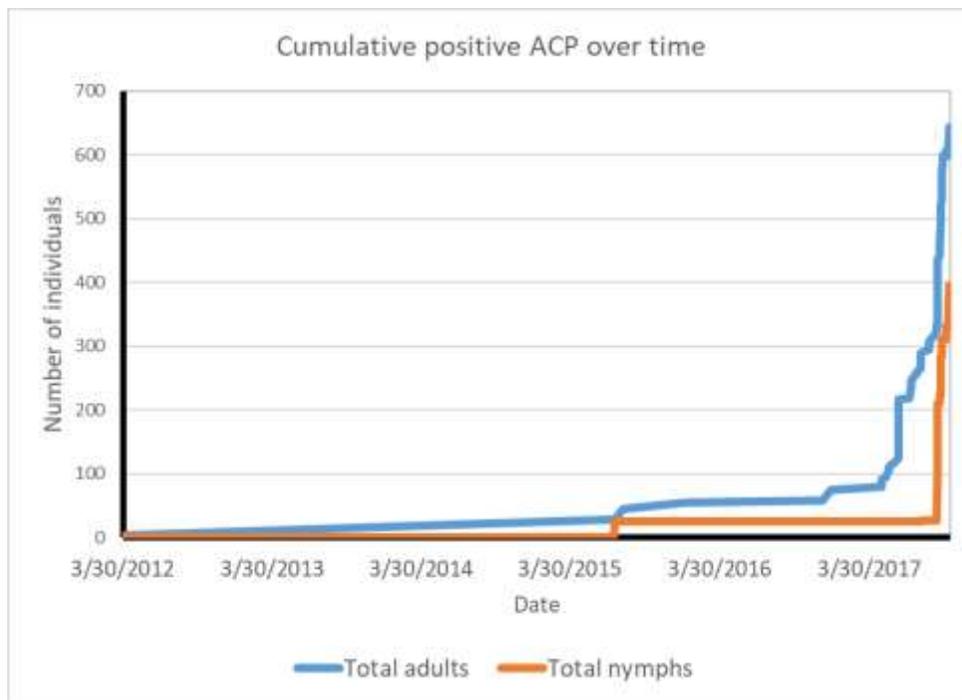


Figure 4: Cumulative counts of PCR-positive ACP samples collected in California over time since 2012. Note the sharp increase in the rate of accumulation from mid-2017 onwards.

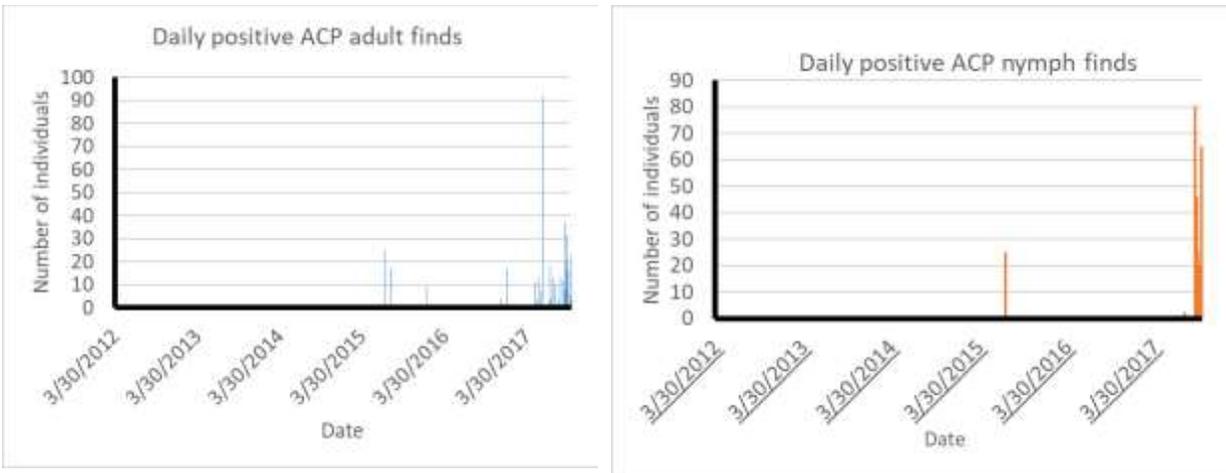


Figure 5: Daily discovery rate for PCR-positive ACP (adults and nymphs are shown separately). Note the sharp increase in finds toward the end of 2017, particularly for nymphs which had largely been absent from positive samples until recent detections.

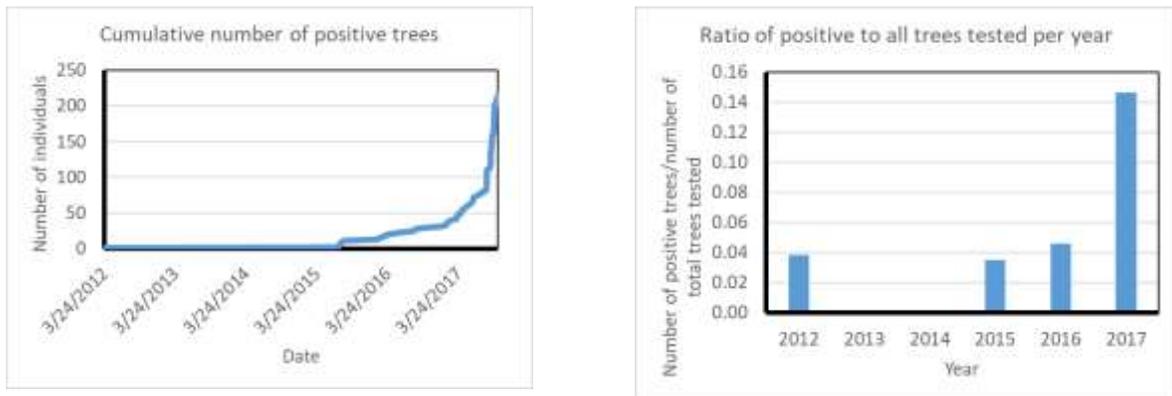


Figure 6: PCR-positive tree detections over time. In the left panel the cumulative number of detections is shown, highlighting the exponential increase in 2017. In the right panel the ratio of positive trees to all trees tested per year is shown. Note that until 2017 the ratio had been more or less stable at approximately 5%, but has nearly tripled in 2017 to just under 15%.

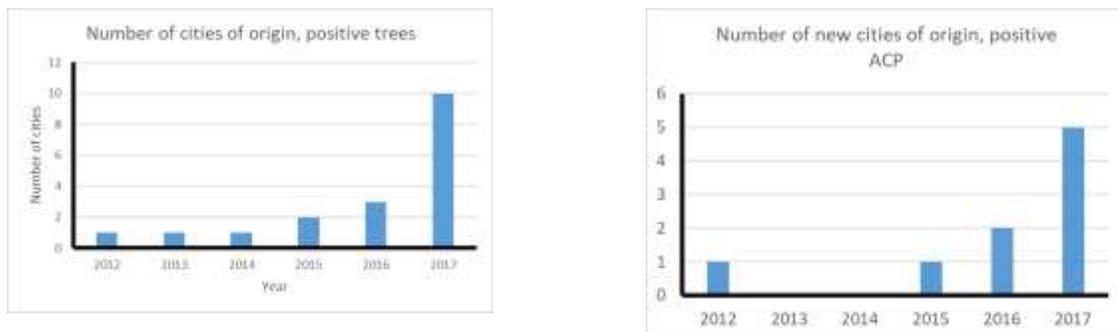


Figure 7: Numbers of cities with PCR-positive ACP detections over time. The left panel shows the cumulative figure, the right panel shows the number of new cities per year. Mirroring the results for trees and for ACP, note the sharp increase in 2017. These results indicate that the epidemic is intensifying across several spatial scales at a very high rate.

Changes in diagnostic results on tested Asian Citrus Psyllids

The previous section detailed the recent sharp increases in PCR detections for ACP and trees. These increases indicate that the pathogen population is growing and this can be seen directly by considering the Ct values in qPCR tests. Results highlighting the increase in the pathogen population are shown here in Figures 8 and 9.

Figure 8 shows the data for qPCR Ct values obtained from psyllid samples collected in different sampling cycles of the survey program. The data are sub-divided into samples obtained from inside and outside the existing HLB quarantine areas. It can be seen that the Ct values obtained from ACP samples inside the quarantine areas are showing a much faster increase in the proportion of low values (CT <32 to 33), indicating an intensification of the pathogen population in the vector population.

The presence of some ACP with low qPCR Ct values outside the existing quarantine areas highlights the risk of ACP moving the disease around and the need for quarantine regulations that apply at a larger scale than the current radius around confirmed HLB-positive trees.

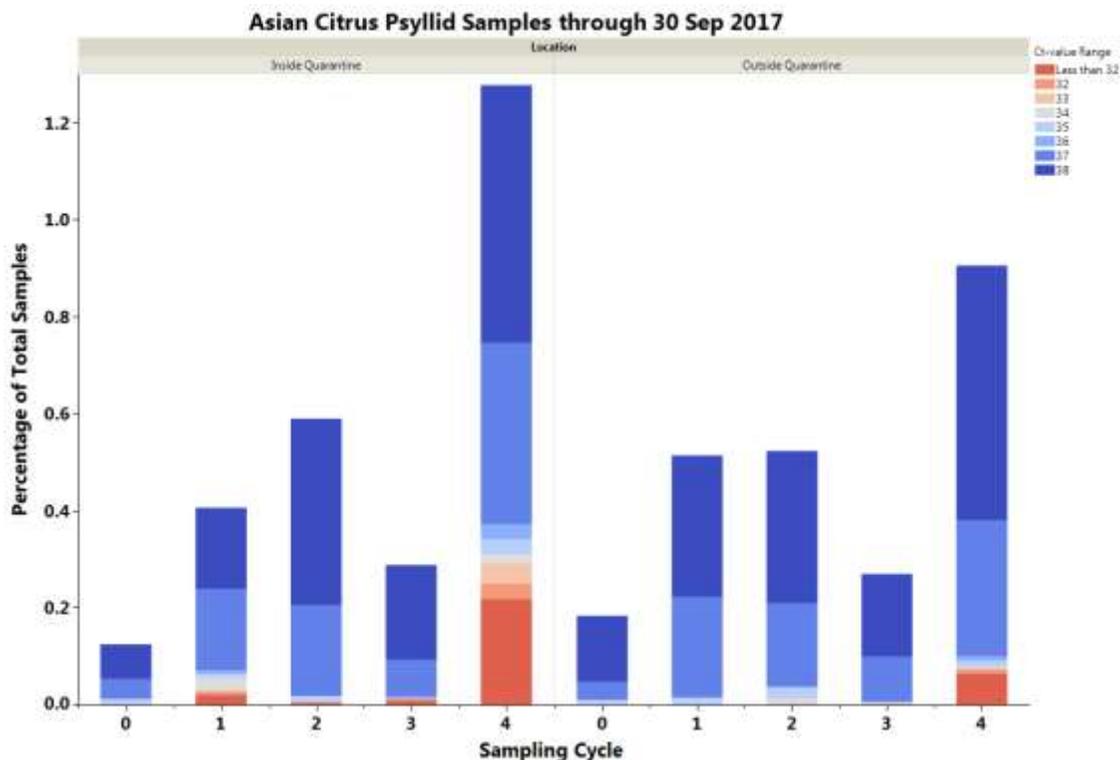


Figure 8: qPCR test results on ACP samples tested by CDFA through 30 September 2017. Note that the proportion of light blue and red (indicating presence of the HLB pathogen) in the samples from inside the quarantine areas (left panel) has increased over time, whereas no corresponding change is apparent in samples outside the quarantine areas (right panel).

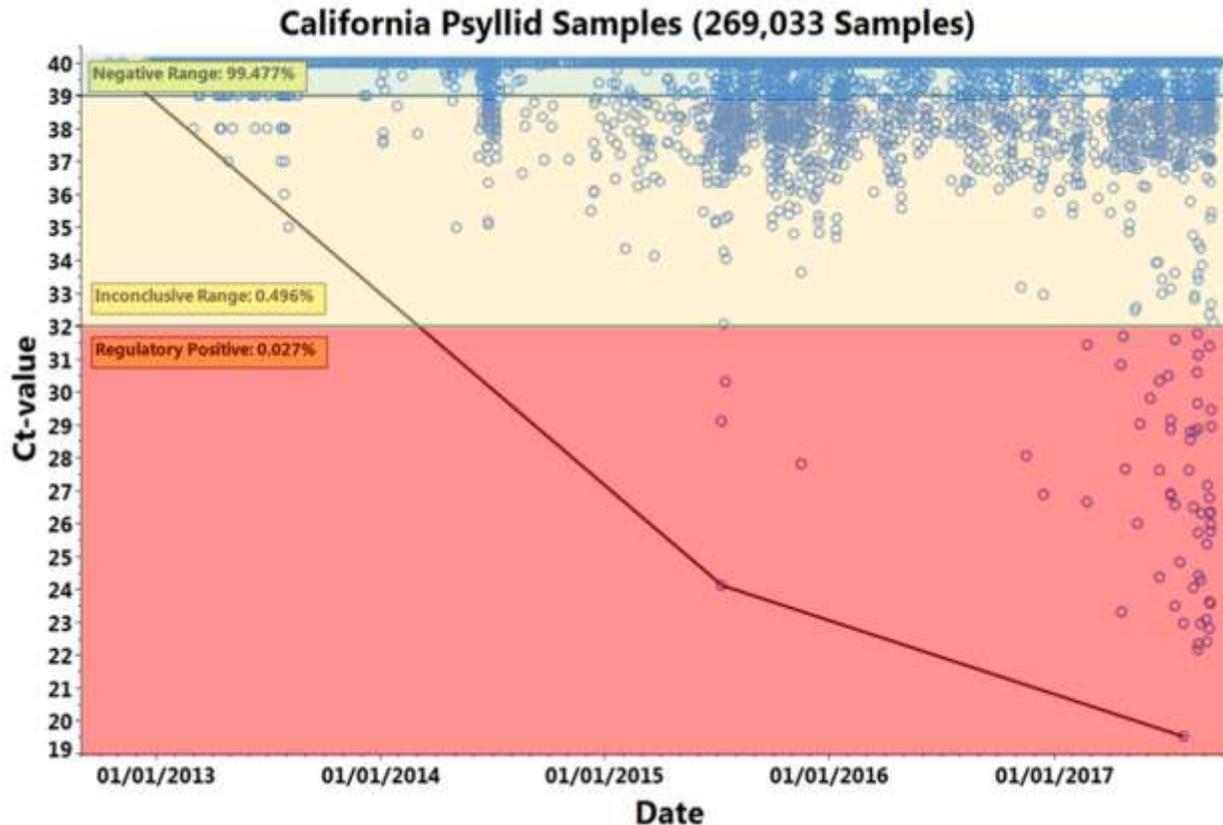


Figure 9: qPCR regulatory results recorded since the detection of HLB in California over time compared to the concentration of the pathogen in the sample (Ct < 32.1= HLB positive (red zone), Ct 32.1-38.9 = suspect (yellow zone), Ct > 38.9=HLB not detected (green zone)). The lower the Ct value, the higher the concentration of the HLB bacterium. Note the trend towards lower Ct values over time and the increase in numbers of HLB positive psyllids starting in 2015 and continuing through 2017 indicating that the titre (concentration) of HLB DNA in the psyllids is increasing.

Implications of changes in the dynamics and recommendations

To summarize the recent changes in the dynamics of HLB/ACP detections in trees and psyllids:

1. The number of HLB positive citrus trees detected has increased exponentially in the last 4 months as compared to the previous 6 years.
2. The number of HLB positive and infectious Asian citrus psyllids has increased exponentially in the last four months as compared to the previous 6 years.
3. These HLB infectious psyllids are spreading to new communities in the LA basin at a significantly escalated rate compared to the previous 6 years.
4. These infectious psyllids can be spread by movement of ACP-host nursery stock, bulk citrus, and other possible carriers of ACP.

Given the above developments in the California HLB epidemic it is of the utmost urgency to further compartmentalize the state using quarantine zones defined by HLB risk to commercial citrus (rather than 5 mile and county wide quarantines). This will help to reduce the potential for spread of HLB to zones where HLB has not been detected in citrus trees, nor has Asian citrus psyllid become established in some cases. The proposal to divide the state into 7 zones for bulk citrus movement and three zones for nursery stock, will serve to restrict the dispersal of HLB and its ACP vectors. Currently all known HLB infected trees are inside a single quarantine zone – zone 6. However, with the exponential escalation of the number of infected ACP and citrus trees requires an immediate regulatory response to restrict spread before the opportunity for such measures to be effective is lost.