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The potential adventive geographic range of glassy-winged sharpshooter, *Homalodisca coagulata* and the grape pathogen *Xylella fastidiosa*: implications for California and other grape growing regions of the world

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Abstract

The invasion risk posed by the xylem feeding hemipteran, *Homalodisca coagulata* (native to the southeast USA and northeast Mexico, and a recent invader of California (USA) and Tahiti) and a xylem-dwelling phytopathogenic bacterium, *Xylella fastidiosa* (native to the Americas and causative agent of Pierce's disease of grape vines), was examined using the computer climate modeling program CLIMEX. Model predictions indicated that suitable climatic conditions for *H. coagulata* and Pierce's disease causing strains of *X. fastidiosa* exist in almost all grape production areas of the world, and *H. coagulata* may be able to colonize areas unsuitable for *X. fastidiosa*. Additionally, the model indicated that regions north of California will be unable to sustain populations of both pests because of cold stress, and that irrigation of agricultural and urban areas in California's deserts has removed dry stress limitations, which when combined with a depauperate natural enemy fauna most likely facilitated successful invasion by *H. coagulata*. CLIMEX predicted that cold stress accumulation would exclude Pierce's disease causing strains of *X. fastidiosa* from France and northern and central grape producing areas of Spain and Italy. This result is incongruous with Pierce's disease reports from Kosovo in the Balkans and may suggest that cold-tolerant strains of *X. fastidiosa* that cause Pierce's disease exist which could exhibit invasion potential and establish in areas of Europe contrary to results reported here.

Keywords: CLIMEX; Invasive species; Pest risk assessment; Incursion management

1. Introduction

The glassy-winged sharpshooter, *Homalodisca coagulata* (Say) (Hemiptera: Cicadellidae) has emerged as a significant adventive threat to California (USA) agriculture since its presumed establishment in southern California in the late 1980s (Sorensen and Gill, 1996). *H. coagulata* is well established throughout southern California and incipient populations have been detected as far north as Sacramento and Butte Counties (Fig. 1). Museum records and foreign exploration expeditions for natural enemies of *H. coagulata* indicate that the home range of this pest includes the southeastern USA and northeastern Mexico (Triapitsyn and Phillips, 2000). It is probable that as biological control efforts against *H. coagulata* in California progress, and foreign exploration continues; the natural range of *H. coagulata* will be subject to further revision and subsequent redelineation.

H. coagulata is polyphagous feeding on over 100 species in 31 families (Hoddle et al., 2003; Turner and Pollard, 1959), xylophagous (Andersen et al., 2003), highly mobile (Blua et al., 2001), and can feed on dormant plant tissue over winter (Purcell and Saunders, 1999). Most importantly, *H. coagulata* vectors *Xylella fastidiosa*, a xylem-dwelling bacterium, which causes a variety of scorch-like diseases in plants of agricultural (e.g., alfalfa, almonds, citrus, coffee, grapes, and peaches (and known as alfalfa dwarf, almond leaf scorch, citrus variegated chlorosis, coffee leaf scorch, Pierce's disease, and phony peach disease, respectively)) and ornamental (e.g., elm leaf scorch, oak leaf scorch, oleander leaf scorch, and sycamore leaf scorch)

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Fig. 1. Current distribution of *H. coagulata* in California, USA. Each county with a permanent *H. coagulata* population has been labeled (black text) and in counties where these populations are still highly localized the generalized area of infestation has been shown. Wine producing counties in northern California at risk of *H. coagulata* infestation are shown in blue. This figure was prepared from information provided by the California Department of Food and Agriculture (California Department of Food and Agriculture, 2003).

importance (Almeida and Purcell, 2003; Blua et al., 1999; Costa et al., 2000; Hopkins and Purcell, 2002; Purcell et al., 1999; Turner and Pollard, 1959). Over 145 strains of *X. fastidiosa* are recognized (Hopkins and Purcell, 2002) and this bacterium appears to be native to the Americas with a range that extends from the USA to South America (Purcell, 1997). *X. fastidiosa* has been present in California since 1884 and vectoring activity by native cicadellid sharpshooters (e.g., blue-green sharpshooter (*Graphocephala atropunctata* (Signoret)) and red-headed sharpshooter (*Xyphon fulgida* (Nottingham))) and spittlebugs (Cercopidae) has resulted in a chronic Pierce's disease problem for grape growers in northern and southern California (Hewitt et al., 1942; Purcell, 1989). The Pierce's disease causing strain of *X. fastidiosa* (referred from hereon as PD-XF) is restricted in the USA to areas with mild winters (i.e., where winter temperatures do not fall below 1–4°C) (Purcell, 1997). Pierce's disease is less prevalent where winter temperatures are colder, such as at higher altitudes, farther inland from moderating ocean influences, and at more northern latitudes. Tropical, sub-tropical and Mediterranean climates appear to be particularly favorable for *X. fastidiosa* persistence and disease outbreaks (Purcell, 1997). Freezing events can be therapeutic for PD-XF infections (Feil and Purcell, 2001; Hopkins and Purcell, 2002).

A major reservoir for *H. coagulata* in California is citrus and Pierce's disease incidence is particularly severe at citrus–grape interfaces (Perring et al., 2001). The establishment of *H. coagulata* has radically changed the epidemiology of Pierce's disease in agricultural and urban systems with disease incidence becoming more prevalent and acute (Almeida and Purcell, 2003). Furthermore, *H. coagulata* may have irrevocably changed the ecology and movement of *X. fastidiosa* in California wilderness areas as this polyphagous insect could be exposing a variety of novel native hosts to a pathogen with which these plants have had no evolutionary history.

In economic terms, grapes are worth \$3.2 billion (US) and associated economic activity exceeds \$33 billion (US) in California. In addition, crops such as almonds, and stone fruit have been valued at \$897 million (US) and \$905 million (US), respectively, and are at risk from strains of *X. fastidiosa* that cause disease in these host plants (California Department of Food and Agriculture, 2003). The *H. coagulata–X. fastidiosa* combination could potentially have a severe and adverse affect on California's agricultural industries and subsequently the state's economy. In 2002, the state of California and primary producers incurred additional economic costs resulting from spread containment activities such as inspections of nursery stock being moved out of southern California, and shipments of bulk grapes and citrus from *H. coagulata* infested counties (California Department of Food and Agriculture, 2003).

A fundamental requirement for the establishment of any species outside of its home range is that the recipient location must have a climate similar to the invader's area of origin. A major and unresolved issue regarding the management of *H. coagulata* concerns its potential geographic range within California and grape growing states north of California (e.g., Oregon), and for this pest to continue its spread beyond the USA and Mexico. One reason for uncertainty over the potential geographic range of *H. coagulata* in California is that pertinent information (e.g., day–degree developmental data) required for assessing invasion risk, successful establishment, and population growth is lacking. Assuming that climate is a major factor affecting establishment success or failure, matching the climate of the home range to potential recipient regions can be used to determine the suitability of areas under invasion risk and subsequent invader spread to vulnerable regions. Additionally, implementation of phytosanitary measures to curb unwanted incursions need to be scientifically justifiable if restrictions are to be in accordance with the Sanitary and Phytosanitary Agreement of the World Trade Organization and the International Plant

Protection Convention. Consequently, if it can be demonstrated that a particular invader cannot extend its range and establish transient populations in an area under consideration then exclusion is not technically justifiable (Baker, 2002).

Climate matching methods range from simple indices that allow graphical comparisons across localities to computer software that match climates and relate species distributions or ecophysiological responses to environmental variables (Worner, 2002). One climate matching computer program is CLIMEX. This is a predictive tool that can be used to ascertain an organism's potential abundance and distribution using biological data, and observations on its known geographical ranges (Sutherst and Maywald, 1985). CLIMEX has been used to determine the potential distribution of natural enemies following release in new locales (Mo et al., 2000), assessing invasion risk posed by exotic cerambycid beetles (MacLeod et al., 2002), determining the potential geographic distribution of economically important tephritid flies (Vera et al., 2002), and elucidating climatic factors limiting the distribution of pestiferous soil mites (Robinson and Hoffmann, 2002). To investigate the potential distribution of *H. coagulata* and PD-XF in California and elsewhere in the world an inferential approach using the climatic response of these pests from existing geographic range and laboratory (where available) data was determined using CLIMEX.

2. Materials and methods

2.1. Overview of the CLIMEX model

CLIMEX integrates weekly responses of a population to climate and calculates annual indices. A hydrological model calculates weekly soil moisture from rainfall data and estimated rates of evaporation. The temperature, moisture, and day length responses (used if diapause is a feature of the organism's biology) are combined to generate a weekly population Growth Index. Growth Indices summarize the species response to prevailing annual temperatures and moisture. Extreme environmental conditions can have an adverse effect on population growth and persistence, and stress indices account for these impacts on the species of interest. Stresses may manifest themselves as either prolonged periods of cold, wet, hot, or dry weather, or combinations of these factors e.g., cold and wet. The standard output for CLIMEX is a series of maps for each computed index of interest showing "dots" at the locations of meteorological stations. The size of the "dot" indicates the relative magnitude of the index. For example, CLIMEX combines growth and stress indices to generate the Ecoclimatic Index (EI), which is scaled from 0 to 100. Locations with an $EI > 25$ are very favorable for population growth and persistence; $EI = 10–25$ are favorable, while EI values <10 indicate areas of marginal suitability. An $EI = 0$ indicates the species cannot persist in an area under average prevailing climatic conditions. However, in years with significant deviation from the norm the environment may be accommodating for certain time periods (Sutherst and Maywald, 1985; Sutherst et al., 1999; Vera et al., 2002). Inferential determination of species distribution based on climate matching can have short comings that need to be considered. First, factors other than climate may influence invasion success. For example, natural enemies, host plant availability, and competitive ecological homologues may exclude an invader even though the climate is accomodating. Second, unusual weather patterns deviating from the normative may result in substantial time periods in locales that are accommodating to an invader. The importance of inter-annual variability can be assessed using the "Compare Years" module to explore the impact of sequential weather phenomena on an organism's performance. The "Compare Locations" module is process oriented and used to predict the climatic suitability of an area for species on a weekly or annual basis over a range of selected locations (Baker, 2002; Kriticos and Randall, 2001).

2.2. CLIMEX model parameters and weather data

The values of CLIMEX parameters used in the "Compare Locations" module for *H. coagulata* were inferred from its current home range (Hoddle et al., 2003; Triapitsyn and Phillips, 2000). This inferential process required consideration of climatic factors most likely to limit the distribution of *H. coagulata* in its home range. This derivation was achieved by fitting curves representing the species' response to the environment to the observed distribution of the species. Consequently, parameter values were manually and iteratively adjusted until the simulated geographic distribution as estimated by EI values coincided with the known distribution of *H. coagulata*. Parameter values used to model the home range distribution of *H. coagulata* are given in Table 1. These parameter values were then fitted using CLIMEX to California and global climate data.

Diseases caused by *X. fastidiosa* tend to be tropical and sub-tropical and PD-XF is either rare or absent from areas of North America with cold winters (Hopkins and Purcell, 2002). The effect of temperature on PD-XF has been studied and data from Feil and Purcell (2001) were used to set parameter values shown in Table 2. A distribution map indicating Pierce's disease severity in the USA (http://www.cnr.berkeley.edu/xylella/page2.html (last accessed November 13, 2003)) was used to verify that output from the "Compare Locations" module in CLIMEX using Table 2 parameters were

Table 1
Parameters used in CLIMEX that provided the best-estimated distribution of *H. coagulata* in its currently defined natural range in the southeastern USA and northeastern Mexico after Triapitsyn and Phillips (2000)[a]

CLIMEX parameter	Value
Soil moisture	
SM capacity	100
Evapotranspiration coefficient	0.8
Temperature	
DV0	0
DV1	12
DV2	31
DV3	35
Moisture	
SM0	0.3
SM1	0.5
SM2	1.75
SM3	2
Cold stress	
TTCS	6
THCS	−0.001
DTCS	2
DHCS	−0.001
TTCS1	0
THCS1	−0.001
Heat stress	
TTHS	33
THHS	0.001
DTHS	10
DHHS	0.001
Dry stress	
SMDS	0.3
HDS	−0.006
Wet stress	
SMWS	2
HWS	0.002

[a] Parameter acronyms and definitions are provided in Sutherst et al. (1999).

Table 2
Parameters used in CLIMEX that provided the best-estimated distribution of the strain *X. fastidiosa* causing Pierce's disease of grapes in its currently defined natural range in the USA: Data used are from Feil and Purcell (2001)[a]

CLIMEX parameter	Value
Soil moisture	
SM capacity	100
Evapotranspiration coefficient	0.8
Temperature	
DV0	5
DV1	12
DV2	34
DV3	37
Moisture	
SM0	0.1
SM1	0.5
SM2	1.75
SM3	2
Cold stress	
TTCS	−1
THCS	−0.001
DTCS	20
DHCS	−0.00025
TTCS1	4
THCS1	0
Heat stress	
TTHS	34
THHS	0.001
DTHS	0
DHHS	0
Dry stress	
SMDS	0.1
HDS	−0.005
Wet stress	
SMWS	2
HWS	0.002

[a] Parameter acronyms and definitions are provided in Sutherst et al. (1999).

predicting distributions that were similar to known ranges for PD-XF infestations.

The California weather data in CLIMEX's MetManager was augmented with an additional 21 sites from the California Irrigation Management Information System (CIMIS). Weather records were used from CIMIS stations only if a minimum of 15 continuous years data existed and all variables (e.g., humidity, rainfall, etc.) required by CLIMEX were available. Additional data for augmenting the Florida weather database in CLIMEX was not available. To better fit the home range model to the known distribution of *H. coagulata* in California, an irrigation module was added to the home range model to overcome dry stress, which was limiting the model's predictions of inhabitable areas for *H. coagulata* that were known to have permanent populations of this pest. The irrigation module was conservatively set to provide 5 mm of water a day over summer to alleviate dry stress. There was no winter irrigation.

The home range models for *H. coagulata* and PD-XF without the irrigation module were fitted to global weather data to identify areas with climatic regimes permissive to pest establishment and survival. Using the model without irrigation enabled conservative identification of regions vulnerable to successful invasion and establishment, and visualization of the potential worldwide distribution of *H. coagulata* and PD-XF.

3. Results

3.1. Modeling the home range of *H. coagulata* and PD-XF in the USA

The parameters used in Table 1 to model the home range of *H. coagulata* produced results that are in accordance with the known geographic range of this insect (Fig. 2) (Triapitsyn and Phillips, 2000). CLIMEX predicted that suitable areas for *H. coagulata* survival exist outside the known USA range by indicating that this insect could survive in coastal areas of southern Virginia and in central Arkansas. The principle factor limiting the northern range of *H. coagulata* in the USA was found to be cold stress in the form of inadequate thermal summation to survive the winter. Furthermore, output from the home range model for *H. coagulata* used by CLIMEX indicated that additional areas in Mexico outside of the known range could be suitable for *H. coagulata* survival. Areas with high EI values indicating climatic suitability for *H. coagulata* lie to the south of the Tropic of Cancer (latitude 23.3° north) in the states of Veracruz and Chiapas, and the Yucatan Peninsula. These areas have not been explored for natural enemies of *H. coagulata*.

For PD-XF, model parameters used in Table 2 produced results in accordance with the known distributions of this pathogen in the southeastern USA and California (Fig. 3). EI values indicate more southern locales are most suitable for PD-XF. These are areas in which disease incidence is most severe (Hopkins and Purcell, 2002) (Fig. 3). Cold stress has a major limiting

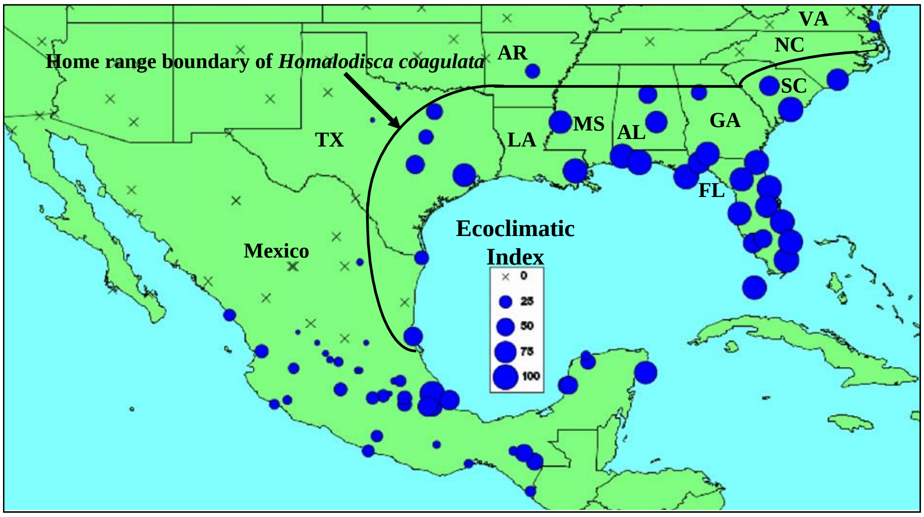

Fig. 2. CLIMEX generated EI values using parameters in Table 1 that optimally model the distribution of *H. coagulata* in its currently defined home range. Abbreviations for USA states are AL = Alabama, AR = Arkansas, FL = Florida, GA = Georgia, LA = Louisiana, MS = Mississippi, NC = North Carolina, SC = South Carolina, TX = Texas, and VA = Virginia.

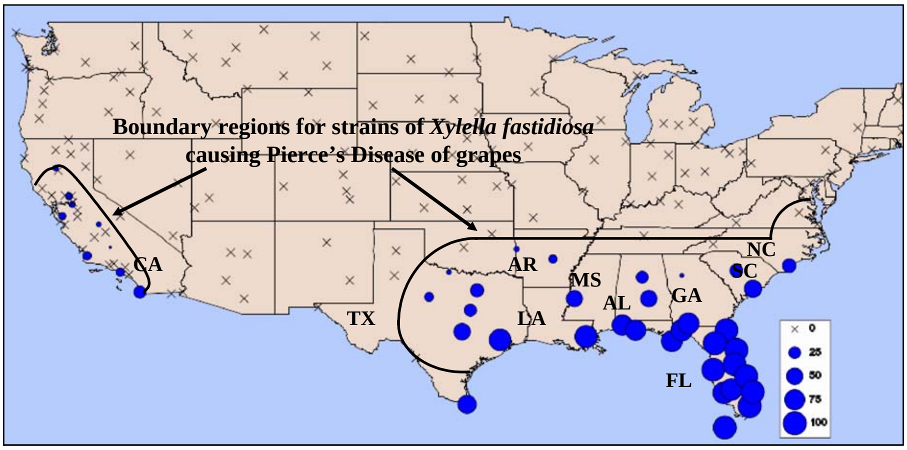

Fig. 3. CLIMEX generated EI values using parameters in Table 2 to model the distribution of the Pierce's disease causing strain of *X. fastidiosa* in the USA. Abbreviations for USA states are AL = Alabama, AR = Arkansas, CA = California, FL = Florida, GA = Georgia, LA = Louisiana, MS = Mississippi, NC = North Carolina, SC = South Carolina, and TX = Texas.

effect on the northward distribution of this disease in the USA. California appears to be the only region in the continental USA outside of the southeastern area that exhibits climatic conditions favorable for severe PD-XF infestations (http://www.cnr.berkeley.edu/xylella/page2.html).

3.2. Application of the home range models for H. coagulata and PD-XF to California

The home range model did not fit the current distribution of *H. coagulata* in California (Fig. 4A and compare to Fig. 1). For example, Los Angeles (County of Los Angeles), Santa Paula (Ventura County), Bakersfield (Kern County), and Visalia (Tulare County) all areas with well-established *H. coagulata* populations were shown to be unsuitable for this pest. Weather station data used by CLIMEX provided dry stress estimates that exceeded tolerable limits for *H. coagulata* in 27 of the 35 localities modeled. Adding an irrigation module to the home range model mitigated dry stress experienced by *H. coagulata.* Water was applied to all sites modeled by CLIMEX in California at a rate of 5 mm per day for summer only. There was no winter irrigation. This conservative summer irrigation schedule created suitable conditions in 28 of 35 areas modeled, including those with known *H. coagulata* populations that were determined as unsuitable when summer irrigation was absent (Fig. 4B compare with Fig. 1). The home range model for PD-XF closely matched areas of California with chronic Pierce's disease problems (Fig. 3).

3.3. Application of home range models to determine the potential global distribution of H. coagulata and PD-XF

CLIMEX indicated that regions with tropical, semi-tropical, mild-temperate, and moderate Mediterranean climates are suitable for habitation by *H. coagulata* and PD-XF (Fig. 5). The model successfully predicted

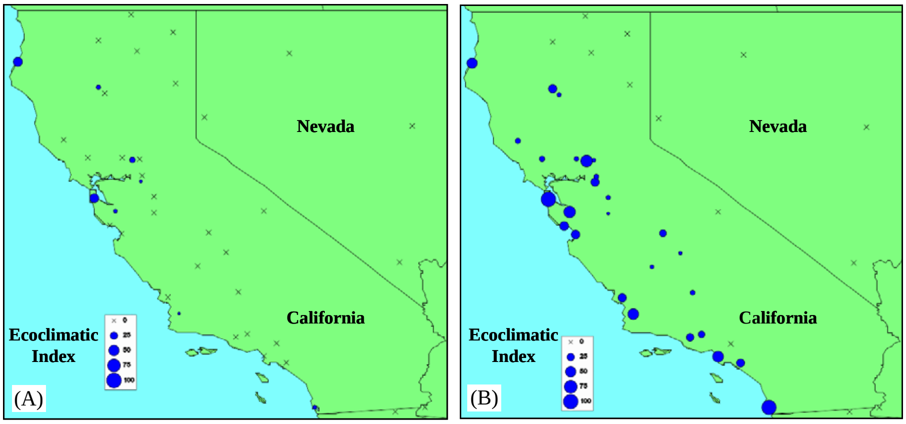

Fig. 4. CLIMEX generated EI values using parameters in Table 1 to model *H. coagulata* distribution in California (A) and the same model with an irrigation schedule applying 5 mm of water per day over summer to reduce the limiting effects of dry stress thereby more accurately reflecting the known distribution of *H. coagulata* in California's irrigated agricultural areas (B).

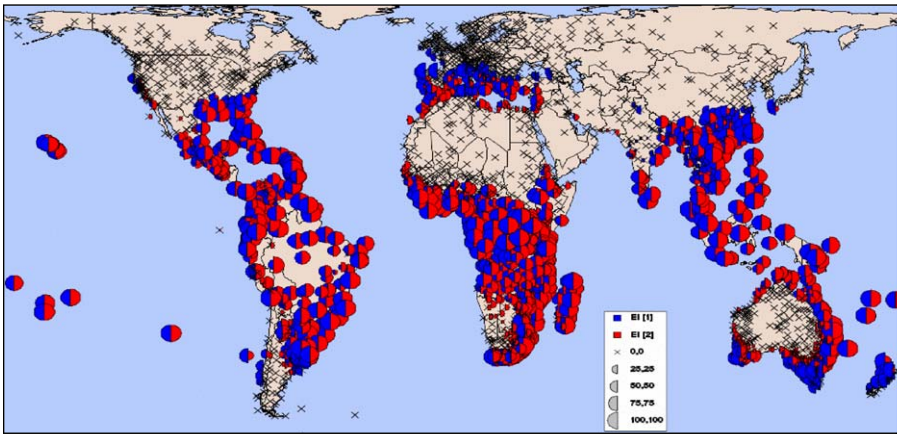

Fig. 5. CLIMEX generated EI values for *H. coagulata* (EI 1 = blue) and the Pierce's disease causing strain of *X. fastidiosa* (EI 2 = red) from parameters in Tables 1 and 2 to model the potential global distribution of these two species.

French Polynesia (Papéete) as being suitable for *H. coagulata*, an area recently invaded by this pest (Plant Protection Service, 2002). Additionally, the PD-XF home range model indicated the Baltic regions of Europe were unsuitable because of cold stress accumulation, even though Pierce's disease exists in Kosovo.

The major wine grape growing regions of New Zealand (Nelson–Marlborough area and Hawkes Bay), Australia, (regions in New South Wales, South Australia, Southern West Australia, and Tasmania), the Bordeaux region of France, Spain (appellations of Galicia, País Vasco, Cataluna, Valencia, and Andalucia), and the central and southern grape growing areas of Italy have climatic regimes that can accommodate *H. coagulata.* Cold stress will exclude *H. coagulata* from the Burgundy and Champagne regions of France, and grape-growing provinces in Northern Italy and Central Spain. CLIMEX predicts that cold stress will exclude PD-XF from most of New Zealand's wine production areas, the states of Tasmania and areas of Victoria outside of Melbourne in Australia, all of France, and northern and central areas of Spain and Italy. Grape producing areas of Chile lying between Valparaiso and Concepcion close to the Pacific coast and the Western Cape Province in South Africa would appear to be vulnerable to invasion by *H. coagulata* and PD-XF.

4. Discussion

H. coagulata and *X. fastidiosa* have demonstrated a propensity to spread and to successfully invade areas outside of their natural ranges. Both pests pose a serious threat to alfalfa, almond, citrus, coffee, grape, peach, plum, and oleander production because pathogenic strains of *X. fastidiosa* vectored by *H. coagulata* and other xylophagous insects can severely affect crop production and ornamental plant health (Costa et al., 2000; Hopkins and Purcell, 2002). The CLIMEX model used in this study successfully delineated the home range of *H. coagulata* and PD-XF and recently invaded areas (i.e., Tahiti for *H. coagulata* (Plant Protection Service, 2002)). The home range model for *X. fastidiosa* indicated that the Balkans were unsuitable for PD-XF even though Pierce's disease is present in Kosovo. This result suggests that strains of PD-XF may exist that vary significantly in their cold tolerance. Variation in cold tolerance within strains of *X. fastidiosa* are known to exist. For example, oak leaf scorch is prevalent in the Niagara Peninsula region of Canada, an area subjected annually to severe winter conditions (Hopkins and Purcell, 2002). Exclusion of PD-XF from France because of cold stress is in accordance with Hopkins and Purcell's (2002) observations that PD-XF has not established in France despite the importation of thousands of American grape rootstocks to combat grape phylloxera. Consequently, this anomaly may provide further evidence for the possibility that cold-adapted strains of PD-XF exist, that such a strain is present in Kosovo and would have a competitive advantage over cold-sensitive strains of PD-XF thereby allowing cold-tolerant strains to spread into colder areas of Europe that CLIMEX predicts are unsuitable based on the model parameters in Table 2. Table 2 parameters were derived from studies on *X. fastidiosa* causing Pierce's disease originating from areas with moderate winter temperatures.

The home range model for *H. coagulata* indicated that irrigation of desert areas in California has artificially created habitat suitable for proliferation of this pest; suggested that *H. coagulata* may not be able to permanently advance north of California because of cold stress limitation; and that climatic conditions of most major wine producing regions of the world are vulnerable to invasion by this pest.

CLIMEX indicated that the only suitable area for *H. coagulata* outside of its natural range in the continental USA is California and the climate of the Hawaiian Islands would be readily acceptable to *H. coagulata*. Cold stress accumulation over winter would prevent *H. coagulata* establishing permanent populations in grape growing states north of California (i.e., Oregon and Washington). The potential global distribution of *H. coagulata* as predicted by CLIMEX includes the Caribbean. It is possible that *H. coagulata* is present on Caribbean islands, especially those close to Florida. The Bahamas and Cuba may hold populations of *H. coagulata* and natural enemies as it is conceivable that storm activity could move adult *H. coagulata* from the mainland onto offshore islands and vice versa. Additionally, CLIMEX has predicted that areas in the states of Veracruz, Chiapas, and the Yucatan Peninsula in Mexico are suitable for *H. coagulata.* It is unknown if *H. coagulata* exists in these areas as they have not been surveyed for natural enemies. Future foreign exploration efforts in these regions of Mexico and the Caribbean to search for biological control agents and to further refine current knowledge on the home range of *H. coagulata* is warranted.

The combined *Homalodisca–Xylella* threat to plant health extends beyond agriculture. Because *H. coagulata* is highly polyphagous and this insect readily transmits *X. fastidiosa*, many native plants in the invaded range will not have been exposed to this bacterium and may be very susceptible to infection. Novel host–pathogen associations such as *X. fastidiosa* with native flora may result in new diseases and epidemics as *H. coagulata* feeds on native plants and infects them with *X. fastidiosa*. International movement and disease expression of *X. fastidiosa* outside of the Americas has begun with pear leaf scorch and Pierce's disease being recorded for the first time in Taiwan and Kosovo, respectively (Hopkins and Purcell, 2002).

Theoretically, if *H. coagulata* egg masses arrived on plants in a new area the nymphs that hatch from these eggs would not have *X. fastidiosa* because the bacterium needs to be acquired from the xylem of infected plants via feeding. Furthermore, *X. fastidiosa* is lost from sharpshooter mouthparts each time juveniles molt and bacteria must be reacquired through feeding on infested host plants (Almeida and Purcell, 2003). Consequently, adult sharpshooters are permanently infected with *X. fastidiosa* but adult age affects transmission efficiency (Almeida and Purcell, 2003). Because a wide variety of ornamental plants have been imported into various countries from the Americas it is probable that reservoirs of *X. fastidiosa* exist in countries lacking *H. coagulata* or native sharpshooters that can vector the disease. Potential host plants may harbor *X. fastidiosa* without exhibiting disease symptoms (Hopkins and Purcell, 2002; Purcell, 1997). Consequently, it may be relatively easy for *H. coagulata* to acquire *X. fastidiosa* in new countries after it establishes, proliferates and spreads by feeding on symptomless hosts infected with this bacterium.

The following steps should be considered to mitigate invasion by *H. coagulata* and the subsequent spread of *X. fastidiosa* caused diseases. These ideas are common sense but require a coordinated research effort and cooperation between Governments, scientists, legislators, growers, and the public:

(1) Exotic plants from the Americas that could potentially harbor *X. fastidiosa* need to be identified and a list of potential symptomless reservoir species from the surveys drawn up.
(2) Intensive surveys of commercial plants identified as potential *X. fastidiosa* reservoirs should be made to determine if they harbor the bacterium. Plant species testing positive for the *X. fastidiosa* should have their continued propagation, distribution, and importation carefully managed, and if feasible subjected to eradication.
(3) Potential pathways that could permit *H. coagulata* to reach other countries from French Polynesia and the USA (in particular ornamental plants from California and Florida) need to be identified and intensively monitored. Similarly, potential movement pathways for PD-XF and other strains of *X. fastidiosa* out of California, Florida, Taiwan and Kosovo need to be determined and monitored.
(4) Scientists need to be consulted to identify and list native and exotic xylophagous insect species (i.e., hemipterans in the families Cicadellidae (subfamily Cicadellinae; tribes Cicadellini and Proconiini) Cercopidae, and Cicadidae vector *X. fastidiosa* (Purcell, 1989, 1997)) that have invasion and *X. fastidiosa* vectoring potential. Potential invasion pathways for these insects need to be determined and monitored to contain and eradicate early incursions.
(5) Studies exploring the potential threat *X. fastidioa* poses to native plants in recently invaded ranges should be investigated. This may be relatively easy to do as native plants in invaded areas may be grown as ornamentals in California and Florida and cooperative studies between USA and foreign scientists could be initiated to study the susceptibility of native flora to *X. fastidiosa* and attractiveness to *H. coagulata*.
(6) Further investigation on the effect of cold temperatures on the survivability and infectivity of different strains of *X. fastidiosa* need attention to help predict the likelihood of establishment in areas currently considered ''too cold'' for this bacterium.
(7) Public education programs need to be strengthened to highlight the threat invasive pest species pose to agriculture and wilderness areas, and the unacceptable risks associated with ''sneaking'' in plant material need to be reinforced with severe fines.

Once an exotic insect is established in a new area it can be difficult if not impossible to eradicate if small founding populations are not detected early. Knowledge of existing *X. fastidiosa* reservoirs, identity of potential *X. fastidiosa* vectors and their invasion pathways can form the basis for a sound scientifically based program to identify and proactively manage the risk that the *Homalodisca–Xylella* combination presents as they continue to expand their global range. The current *H. coagulata* situation in northern California is particularly sobering. The likely spread of *H. coagulata* from San José into Napa, Sonoma, and Mendocino Counties is being monitored closely. The impact and subsequent management of *H. coagulata* and *X. fastidiosa* in northern California's premier wine growing regions may be portentous for other grape growing countries of the world that could support this vector and pathogen should they invade and successfully establish.

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