CLIMATOLOGICAL POTENTIAL FOR *SCIRTOTHRIPS DORSALIS* (THYSANOPTERA: THRIPIDAE) ESTABLISHMENT IN THE UNITED STATES

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Abstract

Scirtothrips dorsalis is a serious exotic pest that has recently become established in the continental United States. It is of major concern to regulatory agencies because it has a wide host range and high reproductive potential. A weather-based mapping tool, NAPPFAST, was used to predict potential establishment of *S. dorsalis* in North America. The analysis was based on a degree-day model and cold temperature survival of *S. dorsalis*. The results demonstrated that *S. dorsalis* could potentially produce up to 18 generations and was likely to survive in the southern and western coastal plains of the United States. It is concluded that *S. dorsalis* is likely to be a serious economic pest in the southern United States. Additional maps and information are available at the web site (http://www.nappfast.org).

Key Words: exotic species, insect development, temperature, risk mapping, *Scirtothrips dorsalis*

Resumen

Scirtothrips dorsalis es una importante plaga exotica que se ha establecido recientemente en el continente de los Estados Unidos. La presencia de este insecto es preocupante para las agencias que se encargan de la proteccion fitosanitaria debido a que esta especie tiene una lista amplia de plantas hospederas y un alto potencial reproductivo. Utilizamos el programa de mapeo NAPPFAST (que se basa en temperatura) para predecir las posibles areas de establecimiento de *S. dorsalis* en Norte America. El analisis se baso en un modelo de grados dia y en la supervivencia de *S. dorsalis* a temperaturas bajas. Los resultados demuestran que *S. Dorsalis* potencialmente podria producir hasta 18 generaciones por año y que es probable que sobreviva en las planicies costeras del sur y el oeste de los Estados Unidos. Concluimos que *S. dorsalis*probablemente se convertira en una plaga economica seria para el sur de los Estados Unidos.

Translation provided by the authors.

The chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) is a serious exotic pest that has recently become established in the continental United States. It is a highly polyphagous species with over 100 plant species cited as host plants (Meissner et al. 2005). *Scirtothrips dorsalis* occurs throughout Asia, Australasia, and the Pacific Islands (CABI 2005) and in 2003 was intercepted at the port of Miami, Florida, on a shipment of peppers (*Capsicum* sp.) originating from the Caribbean island of St. Vincent (Skarlinsky 2003). It was subsequently confirmed in St. Vincent, St. Lucia (Skarlinsky 2003; Ciomperlik & Seal 2004), Barbados (Ciomperlik et al. 2005a), Trinidad and Tobago, Puerto Rico (Ciomperlik unpublished data), and in South America in Suriname (Ciomperlik et al. 2005b) and Venezuela (M. Quiros, pers. comm.). In late 2005, *S. dorsalis* was reported in Florida (Hodges et al. 2005) and has been detected 70 times in 16 Florida counties (Holtz 2006). In 2004, APHIS began a comprehensive risk assessment of the potential introduction and establishment of *S. dorsalis* (Meissner et al. 2005).

Scirtothrips dorsalis is estimated to produce up to 8 generations annually in Japan (Tatara 1994); however, its generational potential in the United States is unknown. Although *S. dorsalis* has colonized parts of Florida, the areas where it could potentially survive and establish remain undefined. A predicted establishment map was developed by Venette & Davis (2004) based on a biome matching technique (Olsen et al. 2001). The study predicts that potential establishment in the eastern United States would not include the coastal plain, with the exception of a small area of southern Florida. On the west coast, potential establishment was limited to the Willamette Valley in Oregon.

The biome approach used by Venette & Davis (2004) is an example of an inductive risk mapping technique where the predicted distribution is based on a climate or habitat match (Baker 2002). Inductive risk maps based on climate and host distribution have been used widely to predict potential pest establishment (Sutherst & Maywald 1985; McKenney et al. 2003; Hoddle 2004). Risk maps also are created with deductive techniques that use experimental data to create biological models that predict a pathogen's distribution from weather or climate data (Baker 2002). One deductive approach useful for predicting establishment of exotic insect pests is phenology models (Baker 1991; Jarvis & Baker 2001; Baker 2002). Another approach is to exclude areas where cold or hot temperatures result in pest mortality (Magarey et al. 2007). The comparison of deductive and inductive approaches for the same pest provides additional evidence for decision makers.

Recently, site-specific weather technologies have made it easier to apply pest phenology and weather-based risk models to risk prediction on a regional or national scale. The technology uses spatial interpolations and numerical models to create simulated observations (Russo 1999; Magarey et al. 2001). Site-specific weather technologies have successfully been used to deploy phenological models at the scale of individual farms or at a regional scale for many insects including, apple (*Malus domestica*) pests, gypsy moth (*Lymantria dispar*), root weevils (*Diaprepes abbreviatus*), Monarch butterfly (*Danaus plexippus*), and European corn borer (*Ostrinia nubilalis*) (Russo et al. 1993; Felland et al. 1997; Dively et al. 2004; Dillehay et al. 2005; Lapointe et al. 2007). In this study, a web-based modeling system was used to create potential weather-based pest establishment maps in the United States for *S. dorsalis*.

METHODS

Risk maps for *S. dorsalis* were created by using the standardized procedure for 50 exotic pests listed as priorities by the Cooperative Agricultural Pest Survey program (Borchert & Margosian, unpublished). Climate risk maps were produced based on the North Carolina State University-APHIS Plant Pest Forecast (NAPPFAST) modeling system (Borchert & Magarey 2005; Magarey et al. 2007). The system was built and maintained by a commercial weather company (ZedX, Inc., Bellefonte, PA) with experience in pest modeling and site-specific weather data (Russo 1999). The NAPPFAST system links daily climate and historical weather data with biological models that contain a series of interactive 'fill-in-the-blanks' templates (Borchert & Magarey 2005). The model template was based on one developed for European corn borer (Dillehay et al. 2005) that uses daily weather and climate data from approximately 2000 weather stations across North America. Individual station values are interpolated to a 10 km^2 by using the Barnes method (Barnes 1964). The NAPPFAST system has been validated for Japanese beetle (*Popillia japonica*) (Magarey et al. 2005), *Diaprepes abbreviatus* (Lapointe et al. 2007) and numerous internal APHIS pests risk assessments (Magarey et al. 2005). As NAPPFAST lacks international weather data (outside of North America), validation of the model was limited to the Caribbean.

Based upon the insect development template in NAPPFAST, generation potential maps were created for *S. dorsalis* from 10 years (1994-2004) of the North American climate database. To determine the potential number of generations *S. dorsalis* could complete in a year, the developmental model used parameters of 9.7°C as the base developmental temperature and cumulative degree-day (DD) requirement from oviposition to oviposition of 281°C DD (Tatara 1994). These requirements were similar to those Shibao (1996) used for *S. dorsalis* on grape (*Vitis vinifera*). To illustrate the influence of climate on generation potential, probability maps were developed displaying the frequency of occurrence of 1 to 5 generations. Although *S. dorsalis* will most likely develop more than 5 generations in many areas of the United States, it was assumed that 5 generations represented the biological impact sufficiently. Data which occurred less than 2 out of 10 years were excluded from the maps and the remaining data reclassified (with ArcGIS 8.3, ESRI, Redlands USA) into a single representative class to demonstrate the generational potential of *S. dorsalis*. Ten-year probability maps for generations 1 to 5 were added and divided by 5 to maintain a 10-class scale. A value of 1 represents low occurrence of multiple *S. dorsalis* generations, while a value of 10 indicates *S. dorsalis* has the degree-days required to complete 5 generations.

To define areas in the United States where *S. dorsalis* may potentially establish, maps showing a cold temperature exclusion boundary were created with the 10-year North American climate database in NAPPFAST. The cold temperature exclusion model was developed for when the minimum daily temperature reaches -4°C or below for 5 or more days in a year. These parameters were based on a study of a similar thrips species, *Thrips palmi* (McDonald et al. 2000) because the temperature that is lethal to *S. dorsalis* is unknown. McDonald et al. (2000) presented LD_{90} mortality lethal time data for 3 temperatures; 0°C, -5°C, and -10°C. A threshold of -4°C was used because -10°C occurs infrequently in the southern United States and the LD_{90} at 0°C was over 170 h. Both *S. dorsalis* and *T. palmi* occur frequently as mixed populations in the field (M. Ciomperlik, unpublished data; Chu et al. 2006). A 10-year frequency map showing the cold temperature exclusion boundary was created in NAPPFAST and imported into the GIS. Data were excluded from the maps which occurred less than 8 out of 10 years and the remaining data reclassified into a single representative class.

Mortality of *S. dorsalis* at temperatures above 33°C has been observed, with the mortality rate at 100% after 3 d exposure to 38°C (Tatara 1994). However, constant high temperatures of this magnitude and duration are not generally found in the United States, so a high temperature exclusion boundary was not included. The final climate risk map for *S. dorsalis* was created by overlaying the generation potential map with the cold temperature exclusion boundary.

The density of host crops also determines where insects may potentially establish. Host density risk maps for the United States were created in ArcGIS from county acreage data (USDA NASS 2002). The analysis was restricted to the top 30 agricultural commodities by value. Host determination and host status (primary versus secondary) (Table 1) was obtained from information in the APHIS Global Pest Disease Database, which was primarily sourced from the CABI Crop Compendium (CABI 2005). Total primary and secondary host acres were divided by the total acres per county, re-classed into 10 classes based on the classification scheme in Table 2 and combined in a 2 (primary):1 (secondary) weighted analysis. The scale of 1 to 10 describes the proportion of total host acreage per county: for example a rank of 1 indicates no host acreage, while a score of 10 indicates that 75-100% of the acres in the county contains suitable hosts for the pest.

A final risk map representing the influence of both climate and host was created in the GIS. The host risk map (Fig. 1) and the climate risk map (Fig. 2) were multiplied by 0.34 and 0.66, respectively, and added together to obtain a final risk map (Fig. 3). These values were selected to give greater importance to the host layer.

RESULTS

The greatest density of susceptible hosts includes the Gulf Coast of Texas, southern Florida, the lower Mississippi valley, and the central valley of California (Fig. 1). In areas where *S. dorsalis* could potentially establish or has already established, the major host crops of peppers (*Capsicum annum*), eggplant (*Solanum melongena*),

TABLE 1. HOST SPECIES FOR *SIRTOTHRIPS DORSALIS* (CABI 2005).

Host	Status
Almonds (*Prunus dulcis*)	
Apples (*Malus* spp.)	
Asparagus (*Asparagus* spp.)	Primary
Barley (*Hordeum* spp.)	
Beans (*Phaseolus* spp.)	Primary
Broccoli (*Brassica oleracea*)	
Cantaloupes (*Cucumis* spp.)	Primary
Carrots (*Daucus carota*)	Primary
Celery (*Apium graveolens*)	
Citrus (*Citrus* spp.)	Secondary
Corn (*Zea* spp.)	Primary
Cotton (*Gossypium* spp.)	Secondary
Cucumbers (*Cucumis* spp.)	Primary
Grapes (*Vitis* spp.)	Primary
Lettuce (*Lactuca* spp.)	
Oats (*Avena* spp.)	
Onions (*Allium* spp.)	Secondary
Peaches (*Prunus persica*)	Primary
Peanuts (*Arachis* spp.)	Secondary
Pears (*Pyrus* spp.)	Primary
Potatoes (*Solanum* spp.)	Primary
Rice (*Oryza* spp.)	
Sorghum (*Sorghum* spp.)	
Soybeans (*Glycine* spp.)	Primary
Strawberries (*Fragaria* spp.)	Primary
Sunflower (*Helianthus* spp.)	Primary
Tomatoes (*Lycopersicon* spp.)	Secondary
Wheat (*Triticum* spp.)	
Pine (*Pinus* spp.)	
Other Softwood Trees	
Soft Hardwood Trees	Primary
Hardwood Trees	Primary

TABLE 2. RECLASSIFICATION SCHEME FOR HOST PROPORTION DATA.

Proportion of host acres per county	Host reclassification value
0	1
0-0.01	2
0.01-0.025	3
0.025-0.05	4
0.05-0.075	5
0.075-0.1	6
0.1-0.25	7
0.25-0.5	8
0.5-0.75	9
0.75-1	10

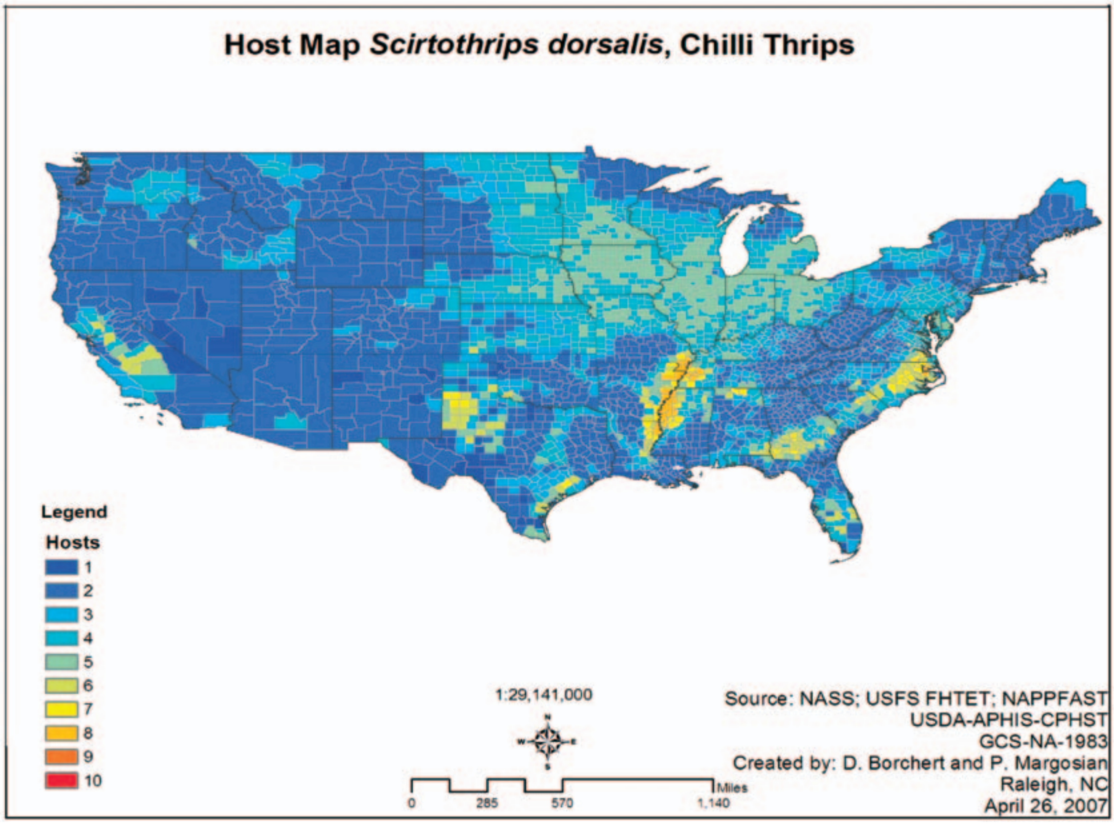

Fig. 1. Host density map risk map for *S. dorsalis*.

and tomatoes (*S. lycopersicum*) predominately are grown in California and southern Florida.

Based on the NAPPFAST analysis, *S. dorsalis* has a high generation potential throughout the United States (Fig. 2). In the southern states of South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas, *S. dorsalis* may produce 12 or more generations annually. Conversely, 4 to 10 generations were predicted on the West Coast of the United States, with increased potential in southern California, Nevada, and Arizona.

The final risk map incorporates host density, generation potential, and cold temperature exclusion (Fig. 3). Due to its exclusion from cold climate areas (where minimum daily temperature reaches -4°C or below on at least 5 d per year), analysis suggests that *S. dorsalis* would probably only establish in the southern United States and along the west coast. Areas of the Caribbean where *S. dorsalis* has been reported; St. Vincent, St. Lucia, Barbados, Trinidad and Tobago, Puerto Rico (Skarlinsky 2003; Ciomperlik & Seal 2004; Ciomperlik et al. 2005a, b; Ciomperlik, unpublished data), all had favorable DD accumulations (18 generations or more) and no cold climate areas (results not shown).

Discussion

The development of risk maps to predict the establishment areas in the United States of *S. dorsalis* demonstrates how NAPPFAST can be used to aid pest risk assessment. The analysis suggests that if *S. dorsalis* were to establish in the United States, it will have a high generational potential and could potentially produce up to 18 generations in regions where cold temperatures are predicted not to preclude *S. dorsalis* establishment. However, the model does not account for environmental factors such as shorter day length, which could induce diapauses response and therefore reduce the generational ability of *S. dorsalis*. The model also does not account for seasonal migration and greenhouse production that could make it a pest beyond the northern boundary of establishment.

Alternative issues relating to the prediction of pest establishment based on phenology models also need to be considered. For example, the NAPPFAST model does not include any latitudinal adjustments that would account for increased development rates at higher temperatures (Rock et al. 1993). The model also assumes that the thresholds published in the literature are correct. Rock

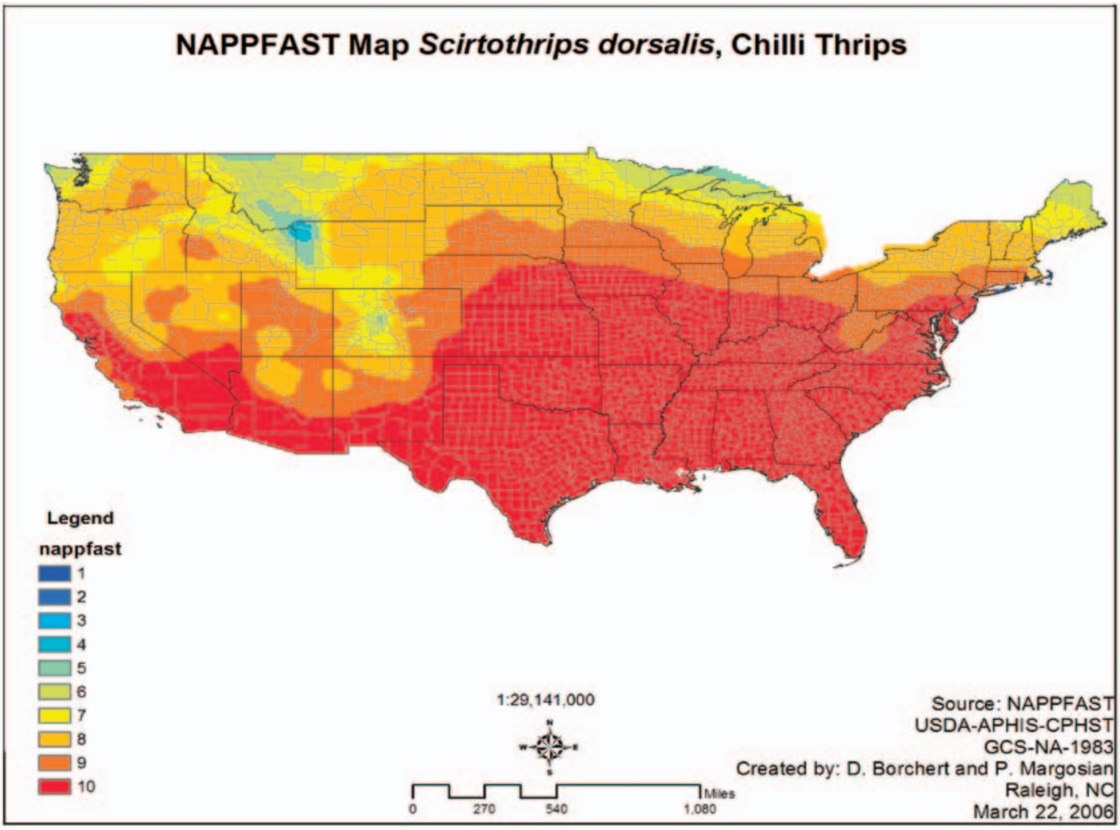

Fig. 2 Ten-year climate risk map for *S. dorsalis* based upon the average frequency of 1-5 generations.

et al. (1993) raise the question that laboratory derived thresholds may under-estimate generation potential in the field due to microclimate differences. Although the thresholds used for *S. dorsalis* were field derived (Tatara 1994), the exact timing of phenological events is not critical for predicting pest establishment, but rather the relative totals. A high generation potential does not guarantee that a pest will reach high population levels; rather it indicates that temperature accumulation is not a limiting factor.

Other environmental factors such as rainfall also may affect the generational potential of *S. dorsalis*, based on studies from India (Varadharajan & Veeravel 1995; Lingeri et al. 1998) that suggest populations may be reduced in high or intense rainfall regions. The level or intensity of rainfall required to reduce populations and the subsequent affect on the generational potential of *S. dorsalis* is unclear. Nevertheless, it is anticipated that *S. dorsalis* will mainly achieve pest status during periods of low rainfall (Mound & Palmer 1981) and thrive under hot, dry conditions. This confirms the assumption that that high temperature mortality will probably not be important in the United States. It is unclear if low humidity (~20%) also will be deleterious to *S. dorsalis* populations (as occur in the Imperial Valley of southern California). This effect has been documented on western flower thrips (*Frankliniella occidentalis*) in the Arava Valley of Israel (Chyzik & Orna-Ucko 2002), but was complicated by the influence of irrigation and cropping systems.

The generation potential of *S. dorsalis* coupled with the wide distribution of host crops increases the likelihood of *S. dorsalis* establishment and its potential to cause economic damage in the United States. Additionally, its major host crops of peppers, eggplant, and tomatoes predominately are grown in California and southern Florida, regions where *S. dorsalis* are predicted to produce a high (10 to 18) number of generations annually. *Scirtothrips* species including *S. dorsalis* particularly cause economic damage to crops when temperatures are high over summer (Hoddle 2002). Because *S. dorsalis* has a short life cycle of 15-20 d (CABI 2005) and is a known pest problem in Japan where it produces up to 8 generations annually (Tatara 1994), it may be assumed that crop regions where *S. dorsalis* completes 8 or more generations face a reasonable chance of sustaining economic damage. This includes regions

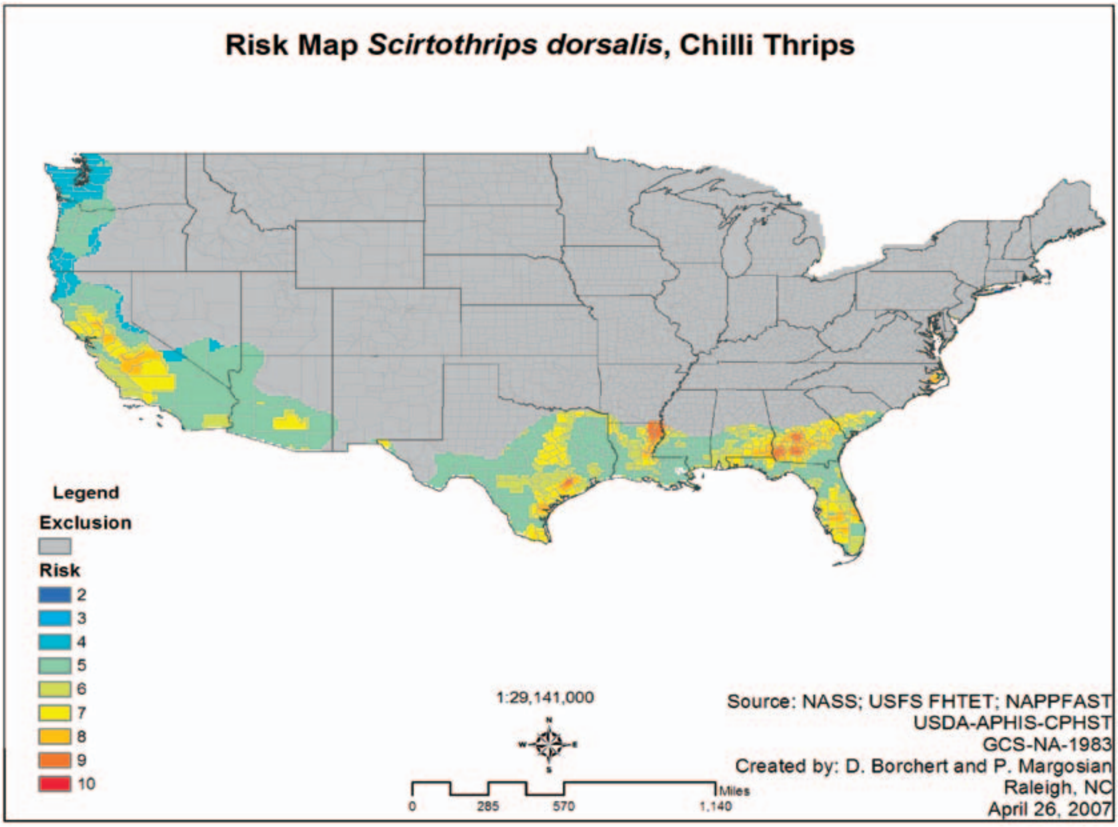

Fig. 3. Risk map for *S. dorsalis* based on generation potential, minimum temperature exclusion, and host density.

where *S. dorsalis* occurs, but may not permanently establish.

Comparisons may be drawn between *S. dorsalis* and *T. palmi* through this study. This is relevant since *T. palmi* has established in Florida, but has not been reported in other U.S. states (CABI 2005). Both *T. palmi* and *S. dorsalis* have a similar geographical distribution and attack many of the same host plants, although *S. dorsalis* has a wider host range than *T. palmi*. *Thrips palmi* has a similar base and DD requirement (10.1°C, 197°C DD, McDonald et al. 2000) to *S. dorsalis* (9.7°C, 281°C DD, Tatara 1994). Because the developmental biology of both species is similar, their restriction to Florida suggests this study over estimates the potential establishment range for *S. dorsalis*. However, it cannot be assumed that *T. palmi* has reached its full establishment potential or that *S. dorsalis* will follow a similar establishment pattern. *Scirtothrips dorsalis* appears to be a more aggressive pest than *T. palmi* in Caribbean field studies (Ciomperlik, unpublished data), causing increased feeding damage to several host crops. Moreover, *S. dorsalis* is likely to be more damaging than *T. palmi* with respect to vegetable, ornamental and fruit crops, and to native plants in natural ecosystems. This is currently the case in southern Florida, where *S. dorsalis* is causing significant damage in ornamental landscapes (Lance Osborne, pers comm.). In addition, *S. dorsalis* has recently been found in damaging population levels in Barbados on sea island cotton (*Gossypium barbadense*), which suggests that it could become a serious pest of cotton (*G. hirsutum*) in North America. Another concern is that *S. dorsalis* is a vector of Tomato Spotted Wilt Virus, which is a serious disease with a large host range (Venette & Davis 2004).

Due to NAPPFAST's lack of international weather daily data, the phenology or cold temperature exclusion model could not be generated outside of North America. With the exception of Japan and Korea, *S. dorsalis* is mostly reported in tropical countries (CABI 2005), making validation difficult unless geographic locations of *S. dorsalis* observations are known.

The results of this study differs from Venette & Davis (2004), who used an inductive biome approach (Olson et al. 2001) to predict establishment of *S. dorsalis* in the north-east and Great

Lakes, but not on the coastal plain of the U.S. Venette & Ragsdale (2004) used a biome approach to predict the distribution of soybean aphid (*Aphis glycines*) in the United States Their results provided a good first estimate but did not forecast the establishment of soybean aphid in central and northern Illinois, the Dakotas and Nebraska. The advantage of the Olson technique is that it is ecologically based rather than only using temperature as in our study. However, the Olson technique has relatively coarse resolution (Thuiller et al. 2005).

It is our conclusion, that *S. dorsalis* is likely to be a serious economic pest and may become established throughout the Caribbean, and in many parts of southern United States and the west coast.

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