

CLIMATOLOGICAL POTENTIAL FOR *SCIRTOTHRIPS DORSALIS* (THYSANOPTERA: THIRIPIDAE) 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 exótica 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 protección fitosanitaria debido a que esta especie tiene una lista amplia de plantas hospedadoras y un alto potencial reproductivo. Utilizamos el programa de mapeo NAPPFAST (que se basa en temperatura) para predecir las posibles áreas de establecimiento de *S. dorsalis* en Norte América. El análisis se basó en un modelo de grados día y en la supervivencia de *S. dorsalis* a temperaturas bajas. Los resultados demuestran que *S. Dorsalis* potencialmente podría 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 convertirá en una plaga económica 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 (NAPPPAST)

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 NAPPPAST 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 km² by using the Barnes method (Barnes 1964). The NAPPPAST 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 NAPPPAST lacks international weather data (outside of North America), validation of the model was limited to the Caribbean.

Based upon the insect development template in NAPPPAST, 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 NAPPPAST. 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 LD₉₀ 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 LD₉₀ 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. dorsa-*

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

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

lis could potentially establish or has already established, the major host crops of peppers (*Cap-sicum annum*), eggplant (*Solanum melongena*),

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

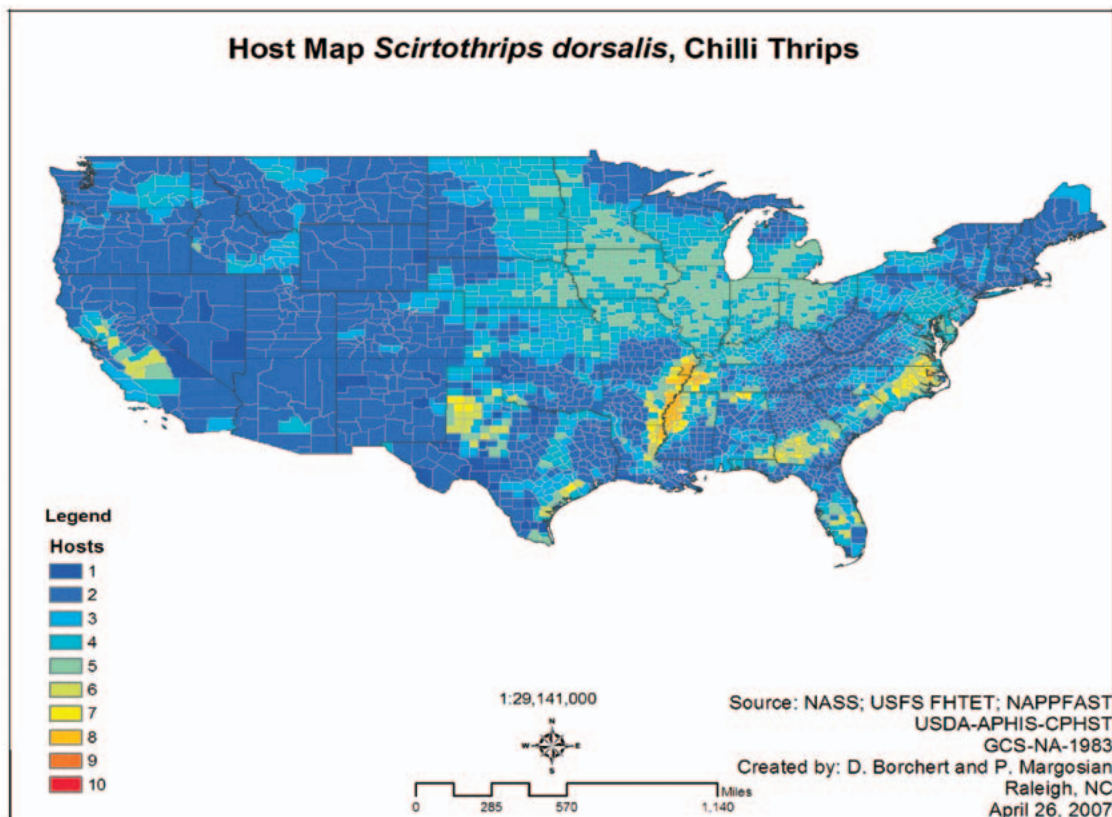


Fig. 1. Host density map risk map for *S. dorsalis*.

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

Based on the NAPFFAST 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 NAPFFAST 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 diapause 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 NAPFFAST 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

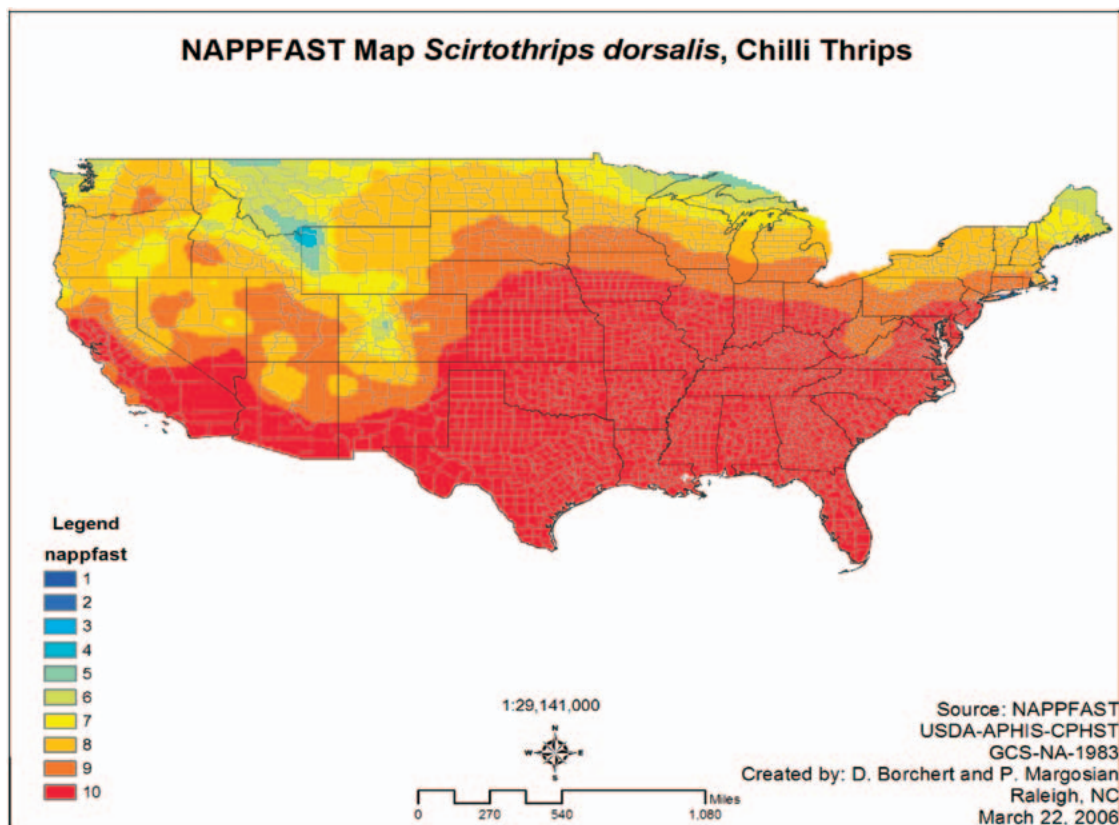


Fig. 2 Ten-year climate risk map for *S. dorsalis* based upon the average frequency of 1-5 generations.

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 (Varadhara-jan & Veeravel 1995; Linger 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

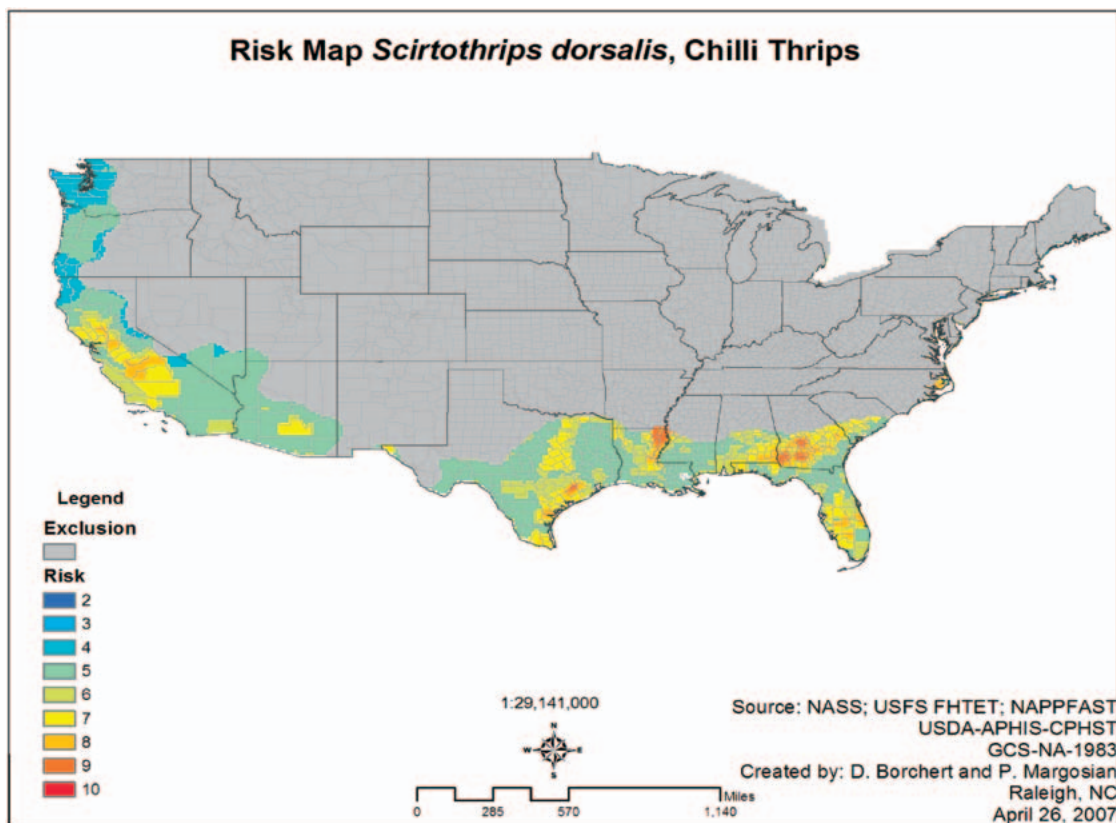


Fig. 3. Risk map for *S. dorsalis* based on generation potential, minimum temperature exclusion, and host density.

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, Tataru 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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REFERENCES CITED

- BAKER, C. R. B. 1991. The validation and use of a life-cycle simulation model for risk assessment of insect pests. *EPPO Bull.* 21: 615-622.
- BAKER, R. H. A. 2002. Predicting the limits to the potential distribution of alien crop pests, pp. 208-241. In G. J. Hallman and C. P. Schwalbe [eds.], *Invasive Arthropods in Agriculture*, Science Publishers, Enfield, NH.
- BARNES, S. L. 1964. A technique for maximizing details in numerical weather map analysis. *J. Appl. Meteorol.* 3: 396-409.
- BORCHERT, D. M., AND R. D. MAGAREY. 2005. A guide to the use of NAPPFAST (<http://www.nappfast.org/usermanual/nappfast-manual.pdf>).
- CABI. 2005. *Crop Protection Compendium*. Wallingford, UK, CAB International.
- CHU C. C., M. A. CIOMPERLIK, N. CHANG, M. RICHARDS, AND T. J. HENNEBERRY. 2006. Developing and evaluating traps for monitoring *Scirtothrips dorsalis* (Thysanoptera: Thripidae). *Florida Entomol.* 89: 47-55.
- CHYZIK, R., AND J. ORNA-UCKO. 2002. Seasonal abundance of the western flower thrips *Frankliniella occidentalis* in the Arava Valley of Israel. *Phytoparasitica* 30: 335-346.
- CIOMPERLIK, M. A., AND D. SEAL. 2004. Surveys of St. Lucia and St. Vincent for *Scirtothrips dorsalis* Hood, January 14-23, 2004. Edinburg, TX, USDA-APHIS-PPQ-CPHST-PDDML. 19 pp.
- CIOMPERLIK, M. A., I. H. GIBBS, J. CARLSON, AND B. TAYLOR. 2005a. Surveys of Barbados for *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) Sep. 17-25, 2005. USDA APHIS PPQ CPHST, Technical Report. 8 pp.
- CIOMPERLIK, M. A., M. JAGAROEP, AND A. VAN-SAUER MUELLER. 2005b. A Survey Report for *Scirtothrips dorsalis* Hood in Suriname. USDA APHIS PPQ CPHST, Technical Report. 8 pp.
- DILLEHAY, B. L., D. D. CALVIN, G. W. ROTH, J. A. HYDE, G. A. KULDAU, R. J. KRATOCHVIL, J. M. RUSSO, AND D. G. VOIGHT. 2005. Verification of a European corn borer (Lepidoptera: Crambidae) loss equation in the major corn production region of the Northeastern United States. *J. Econ. Entomol.* 98: 103-112.
- DIVELY, G. P., R. ROSE, M. K. SEARS, R. L. HELLMICH, D. E. STANLEY HORN, D. D. CALVIN, J. M. RUSSO, AND P. L. ANDERSON. 2004. Effects on monarch butterfly larvae (Lepidoptera: Danaidae) after continuous exposure to Cry1Ab-expressing corn during anthesis. *Environ. Entomol.* 33: 1116-1125.
- FELLAND, C. M., J. W. TRAVIS, J. M. RUSSO, W. C. KLEINER, AND E. G. RAJOTTE. 1997. Validation of site-specific weather data for insect phenology and disease development in Pennsylvania apple orchards. *PA. Fruit News* 77: 10-17.
- HODDLE, M. S. 2002. Developmental and reproductive biology of *Scirtothrips perseae* (Thysanoptera: Thripidae): a new avocado pest in California. *Bull. Entomol. Res.* 92: 279-285.
- HODDLE, M. S. 2004. 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. *Crop Protect.* 23: 691-699.
- HODGES, G., G. B. EDWARDS, AND W. DIXON. 2005. Chilli Thrips *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) A New Pest Thrips for Florida. Florida Department of Agriculture and Consumer Service, Department of Primary Industries. On-line publication at <http://www.doacs.state.fl.us/pi/enpp/ento/chillithrips.html>
- HOLTZ, T. 2006. *Scirtothrips dorsalis* (Hood) New Pest Advisory Group Report, Center for Plant Health Science and Technology, https://www.wpdn.org/%5Ccommon%5Cpest_docs%5Cscirtothrips_dorsalis%5CScirtothrips_dorsalis_NPAG_et_Report_060310.pdf
- JARVIS, C. H., AND R. H. A. BAKER. 2001. Risk assessment for nonindigenous pests, I. Mapping the outputs of phenology models to assess the likelihood of establishment. *Divers. Distrib.* 7: 223-235.
- LAPOINTE, S. L., D. M. BORCHERT, AND D. G. HALL. 2007. Effect of low temperatures on mortality and oviposition in conjunction with climate mapping to predict spread of the root weevil *Diaprepes abbreviatus* and introduced natural enemies. *Environ. Entomol.* 36: 73-82.
- LINGERI, M. S., J. S. AWAKNAVAR, S. LINGAPPA, AND K. A. KULKARNI. 1998. Seasonal occurrence of chilli mites (*Polyphagotarsonemus latus* Banks) and thrips (*Scirtothrips dorsalis* Hood). *Karnataka J. Agric. Sci.* 11: 380-385.
- MAGAREY, R. D., D. M. BORCHERT, G. L. FOWLER, T. B. SUTTON, M. COLUNGA-GARCIA, AND J. A. SIMPSON. 2007. NAPPFAST, an Internet System for the Weather-based Mapping of Plant Pathogens. *Plant Dis.* 91: 336-345.
- MAGAREY, R. D., R. C. SEEM, J. M. RUSSO, J. W. ZACK, K. T. WRIGHT, J. W. TRAVIS, AND P. V. OUDEMANS. 2001. Site-specific weather information without on-site sensors. *Plant Dis.* 85: 1216-1226.
- MAGAREY, R., C. THAYER, D. BORCHERT, AND G. FOWLER. 2005. Weather-based Pest Risk Mapping Project. Annual Report 2005 USDA-CPHST-PERAL/NCSU. <http://www.nappfast.org>
- MCDONALD, J. R., J. HEAD, J. S. BALE, AND K. F. A. WALTERS. 2000. Cold tolerance, overwintering and

- establishment potential of *Thrips palmi*. *Physiol. Entomol.* 25: 159-166.
- MCKENNEY, D. W., A. A. HOPKIN, K. L. CAMPBELL, B. G. MACKEY, AND R. FOOTIT. 2003. Opportunities for improved risk assessments of exotic species in Canada using bioclimatic modeling. *Environ. Monitor. Assess.* 88: 445-461.
- MEISSNER, H., A. LEMAY, A. NEELEY, D. BORCHERT, B. NIETSCHKE, C. BRODAL, AND T. DOBBS. 2005. Evaluations of Possible Pathways of Introduction for *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) from the Caribbean into Continental United States. Pest Risk Assessment by Plant Epidemiology and Risk Assessment Laboratory, USDA Raleigh, NC. 125 pp.
- MOUND, L. A., AND J. M. PALMER. 1981. Identification, distribution and host plants of the pest species of *Scirtothrips* (Thysanoptera: Thripidae). *Bull. Entomol. Res.* 71: 67-79.
- OLSON, D. M., E. DINERSTEIN, E. D. WIKRAMANAYAKE, N. D. BURGESS, G. V. N. POWELL, E. C. UNDERWOOD, J. A. D'AMICO, I. ITOUA, H. E. STRAND, J. C. MORRISON, C. J. LOUCKS, T. F. ALLNUTT, T. H. RICKETTS, Y. KURA, J. F. LAMOREUX, W. W. WETTENGEL, P. HEDAO, AND K. R. KASSEM. 2001. Terrestrial ecoregions of the world: a new map of life on earth. *BioScience* 51: 933-938.
- ROCK, G. C., R. E. STINNER, J. E. BACHELER, L. A. HULL, AND H. W. HOGMIRE, JR. 1993. Predicting geographical and within-season variation in male flights of four fruit pests. *Environ. Entomol.* 22: 716-725.
- RUSSO, J. M. 1999. Weather forecasting for IPM, pp. 453-473 *In* G. G. Kennedy and T. B. Sutton [eds.], *Emerging Technologies for Integrated Pest Management: Concepts, Research, and Implementation*. APS Press, St. Paul.
- RUSSO, J. M., A. M. LIEBHOLD, AND J. G. W. KELLEY. 1993. Mesoscale weather data as input to a gypsy moth (Lepidoptera: Lymantriidae) phenology model. *J. Econ. Entomol.* 86: 838-844.
- SHIBAO, M. 1996. Effects of temperature on development of the Chillie Thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae), on grape. *Appl. Entomol. Zool.* 31: 81-86.
- SKARLINSKY, T. L. 2003. Survey of St. Vincent Pepper Fields for *Scirtothrips dorsalis* Hood. Miami, FL, USDA-APHIS-PPQ, Miami Plant Inspection Station. 5 pp.
- SUTHERST, R. W., AND G. F. MAYWALD. 1985. A computerized system for matching climates in ecology. *Agric. Ecosyst. Environ.* 13: 281-299.
- TATARA, A. 1994. Effect of temperature and host plant on the development, fertility and longevity of *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae). *Appl. Entomol. Zool.* 29: 31-37.
- THULLER, W. D. M. RICHARDSON, P. PYSEK, G. F. MIDGLEY, G. O. HUGHES AND M. ROUGET. 2005. Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biol.* 11: 2234-2250.
- USDA-NASS. 2002. Agricultural Statistics 2002. <http://www.nass.usda.gov/>
- VARADHARAJAN, S., AND R. VEERAVEL. 1995. Population dynamics of chilli thrips *Scirtothrips dorsalis* hood in Annamalainagar. *Ind. J. Ecol.* 22: 27-30.
- VENETTE, R. C., AND E. E. DAVIS. 2004. Chilli Thrips/ Yellow Thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) Mini Pest Risk Assessment. Univ. of Minnesota, St. Paul, MN, USA. 31 pp.
- VENETTE, R. C., AND D. W. RAGSDALE. 2004. Assessing the invasion by soybean aphid when will it end? *Ann. Entomol. Soc. America* 97: 219-226.