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VISUAL PRESENTATION OF THE SPATIOTEMPORAL ASPECTS OF DIAPREPES ROOT WEEVIL EMERGENCE IN A SMALL EAST COAST CITRUS GROVE FROM 2000-2003

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Abstract. **Little is known about the spatial distribution patterns or the rate and direction of spread of *Diaprepes abbreviatus* root weevil infestations in citrus. Weekly adult weevil emergence data obtained from georeferenced Tedders Traps placed in a diamond-shaped grid were projected geographically by means of a Geographic Information System (GIS). The GIS (ESRI ArcGIS) was used to provide spatial interpolation of *Diaprepes abbreviatus* emergence for unmonitored areas for weekly periods for one to four years (2000-2003). Animation software (Macromedia Flash) was then utilized to combine the weekly interpolations into an interactive animation that enabled visualization of the spatiotemporal aspects of *Diaprepes abbreviatus* emergence throughout the entire grove. In addition, these *Diaprepes abbreviatus* abundance interpolations were synchronously aligned with weekly rainfall data. The resultant interactive animation successfully portrayed different geographic and seasonal aspects of *Diaprepes abbreviatus* activity while simultaneously observing rainfall in a smoother transition through space and time than was previously thought possible. The visualization of the spatiotemporal aspects of *Diaprepes abbreviatus* emergence captured by Tedders Traps was much more evident when viewed as an interactive animation than could be derived by more conventional analysis of tabular or graphed data. The ability to visualize additional factors such rainfall or soil temperature in conjunction with spatiotemporal emergence could not only elucidate the ecology of *Diaprepes abbreviatus,* but also result in a fully an Integrated Pest Management (IPM) program by providing essential timing and location information necessary for precision application of crop protectants.**

Diaprepes abbreviatus (Coleoptera: Curculionidae; root weevil) has become established in many crops in Florida, including corn, sugarcane, woody ornamentals, and more than 18% of Florida' commercial citrus acreage is now infested since its discovery in 1964 (McCoy, 1999; Simpson et al., 1996). Since the 1964 discovery of *D. abbreviatus* in Florida (Woodruff, 1964), vast amounts of research has been conducted towards construction of an effective Integrated Pest Management (IPM) program for citrus growers (Hall, 1995, 2000). Still lacking is a meaningful understanding of the ecological relationship between the pest (*D. abbreviatus*) and the fungal pathogen *Phytophthora* spp. This interaction between insect and fungus is known as the Phytophthora-Diaprepes Complex (PDC), and has become increasingly important (Graham et al., 1997). Although the extent of the current impact of PDC to Florida's citrus industry has not been determined, the devastation to a single citrus grove can result in a total loss for the grove owner (Knapp et al., 2001). Specifically, PDC frequently results in tree mortality due to the secondary infection by *Phytophthora* spp. beginning at the lesions produced by larval feeding on the roots (Hall, 2000). Chemical treatments for both insect and fungus are extremely expensive so the ability to provide treatments by prescription application would offer tremendous cost savings to the grower while reducing any environmental impact.

The use of Tedders Traps to capture adult *D. abbreviatus* emerging from the soil has been well documented and can be effective in determining seasonal abundance (Duncan, 2001; McCoy et al., 2003). Basic field parameters such as seasonal abundance, population distribution, and environmental factors like rainfall and soil temperature and their interaction on adult emergence must be determined and analyzed before any successful IPM measures for *D. abbreviatus* can be undertaken (McCoy and Duncan, 2000). Although seasonal abundance data can be depicted with tables and graphs, geographical or spatial distributions of adult population data can best be illustrated with maps typically generated as "views" by a Geographic Information System (GIS). For example, graphs can reveal possible temporal relationships between adult emergence and rainfall, whereas maps illustrate effectively spatial relationships like insect abundance and physical soil parameters such as soil magnesium levels occurring at different locations within a grove (Li et al., 2003). The static abundance maps and line charts created provide geographically accurate results about the status of *D. abbreviatus* distribution within the citrus block but the temporal distribution of such data has to be retrieved from the separate line charts. Such abundance maps based upon trap collection dates also lack any type of temporal alignment with real world environmental factors. Visualization of *D. abbreviatus* distribution in a citrus block cannot be accurately conveyed by such static maps. Up to now, both data forms could not be combined to view both the temporal and spatial distribution of *D. abbreviatus* except as a static view at a specific period of time. Although statistical analysis can validate both spatial and temporal relationships, neither can be displayed together visually.

The goal of this study was to demonstrate the visualization of such spatiotemporal relationships by viewing the weekly spatial interpolations of *Diaprepes* abundance as maps in an interactive animation. Specifically, this animation enabled visualization of the spatiotemporal aspects of *D. abbreviatus* abundance as maps throughout the entire grove along with graphical representations of pest abundance and rainfall over time.

Materials and Methods

A 12.5 acre citrus block named the K-20 block located at the Florida Research Center for Agricultural Sustainability,

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Inc. (FlaRes) in Indian River County, Florida was used as the study site. This block contained 1,492 trees planted in Dec. 1989 with 'Sunburst' tangerine on Swingle citrumelo rootstock using a 4.6 m × 7.6 m (15 ft × 25 ft) spacing and 'Nova' tangelo on Cleopatra mandarin (*C. reticulata* Blanco) as pollinators with 3.8 m × 7.6 m (12.5 ft × 25 ft) spacing. *D. abbreviatus* distribution data were retrieved from 99 Tedders Traps installed in a grid pattern, approximately a 15.2 m × 38.1 m (50 ft × 125 ft), throughout the grove. Tedders Trap bases were obtained from Southeastern Insectaries (Perry, Ga.) and the upper portion of a Boll weevil trap (Great Lakes IPM, Inc., Vestaburg, Mich.) was affixed to the top. Each Tedders Trap was positioned on the south side of the tree at the canopy drip edge, within the tree row (Fig. 1).

All Tedders Traps and trees were georeferenced and entered into a GIS using Environmental Systems Research Institute® (ESRI) personal geodatabase and ArcMap 9.0 software (ESRI, Redlands, Calif.). This geodatabase included feature classes such as the number of captured adult *D. abbreviatus* per trap per week (point), Citrus Tree Location (point), Citrus Tree Variety (point), Citrus Tree Condition (point), Soil Conductivity (point), and Soil pH (point). The feature classes are located under a feature dataset with a projected coordinate system of NAD 1983 HARN UTM. The ESRI personal geodatabase format permitted the use of Microsoft® Access (Redmond, Wash.) interface and Microsoft® Visual Basic for Applications (VBA) programming language capabilities to provide quick data query, manipulation, and analysis. The GIS geodatabase moreover provided a means to spatially establish relationships between feature classes and to temporally align certain feature classes.

The Tedders Traps were monitored weekly and the number of captured adult *D. abbreviatus* was recorded for each trap from 28 Feb. 2000 to 31 Dec. 2003. Captured weevils were destroyed on each date. Previous work by Adair and Dennis (unpublished) showed adult frass from weevils to occur in one of two colors: light-tan or black. Light-tan was found in weevils caught in Tedder's traps, while the black color was from weevils collected through canopy beating. Presumably, the light-tan was due to residual matter from larval root feeding, while the black frass was from foliar feeding. Further, the percentage of adult weevils in the Tedders Traps with light-tan frass was greater than from those captured by canopy beating (29% vs. 5% respectively). Based on this observation, we chose to interpret adult capture by Tedders Traps as an indication of emergence rather than abundance.

Trap count data was entered into the geodatabase as *D. abbreviatus* emergence and relationships were established to the specified Tedders Trap. This emergence data was then assigned a calendar week attribute (1 through 52) based upon the collection date. Any data collected in the 53rd calendar week was rolled over and added to the 1st calendar week of the following year, with the exception of 2003, the last year in this study. Assigning a calendar week allows for alignment of collection data from year to year for temporal spatial analysis.

Interpolated *D. abbreviatus* emergence distribution layers were produced from the 99 weekly trap data points for each week of the year from 2000 to 2003. ESRI ArcMap 9.0 and the Spatial Analyst extension were programmed to generate the raster layers using a weighted Spline with tension (McCoy and Johnston, 2001) at a resolution of 1.524 m (5 ft). The interpolation process was automated using ESRI ArcObjects VBA code to allow for minimum production time. A weighted Spline with tension interpolation method was chosen over other interpolation methods (such as Inverse Distance Weighting, Kridging, or Trend; McCoy and Johnston, 2001) as it produces smooth interpolated raster results with minimum overall surface curvature, does not require intense statistical analysis, and would be most suitable for quick, simple visualization (Hofierka, 2002). Trend removal of the data was not considered as a necessity as visualization of the trend in the data was the final goal. Weighted Spline with tension is an exact interpolation technique where the surface must go through each measured sample value. Conceptually this is similar to fitting a response surface through the Tedders Trap values while minimizing the total curvature of the surface. The selected radial basis function determines how the response surface will fit between the values. Weighted Spline with tension interpolation enabled the ability to create a surface that captures global trends throughout the citrus block and picks up the local variation between Tedders Traps. A weighting value of 20 was used to constrain results towards the sample data range. The interpolation was programmed to the five nearest sample points of each raster cell to determine the value for that cell. Keeping this number relatively low allows for a small localized neighborhood influence on the interpolation results. A total of 200 *D. abbreviatus* distribution raster layers, 44 for year 2000 and 52 for each year from 2001 to 2003, were created for the visualization.

Each raster layer was then visualized using a minimum – maximum stretched renderer classification with visualization values of 1.0 for minimum and 3.0 as maximum. The chosen renderer classification allows for a visualization of areas with a raster value between 1.0 and 3.0 as a gradually fading color and raster values > 3.0 (representing high *D. abbreviatus* emergence) as a solid color. Visualization using this renderer was chosen as a manner of visually "normalizing" the data between years and to best represent areas of high *D. abbreviatus* activity and therefore, a greater risk of damage to surrounding citrus trees. Another benefit of only visualizing *D. abbreviatus* emergence >1.0 is an elimination of *D. abbreviatus* background noise. Interpolated annual total *D. abbreviatus* emergence distribution layers were also produced for each year.

In preparation for the animation production, 208 maps or frames were produced. The 208 weekly maps were exported from ArcMap 9.0 to a Joint Photographic Experts Group (JPEG) image format again using ESRI ArcObjects VBA code to allow for minimum production time. Additional layers were created and added to the image collection. They included Tedders Traps, tree condition, and various soil attributes. The industry standard animation software Macromedia® Flash (San Jose, Calif.) was then incorporated to produce the final animation video by employing the technique of tweening (fading) to interpolate frames between each jpeg image. Use of the tweening technique between frames provides the "temporal interpolation" needed to properly visualize the distribution data. An animation video was produced showing the week to week spatiotemporal aspects of *D. abbreviatus* abundance throughout the citrus block. In addition, a timeline and rainfall graph was introduced to the animation using the Macromedia® Flash software. Calibration of each frame to the timeline was then completed to ensure proper temporal synchronization. The Macromedia® Flash File Format (SWF) version of this animation was integrated into our web pages and can be viewed at www.flaresearch.com.

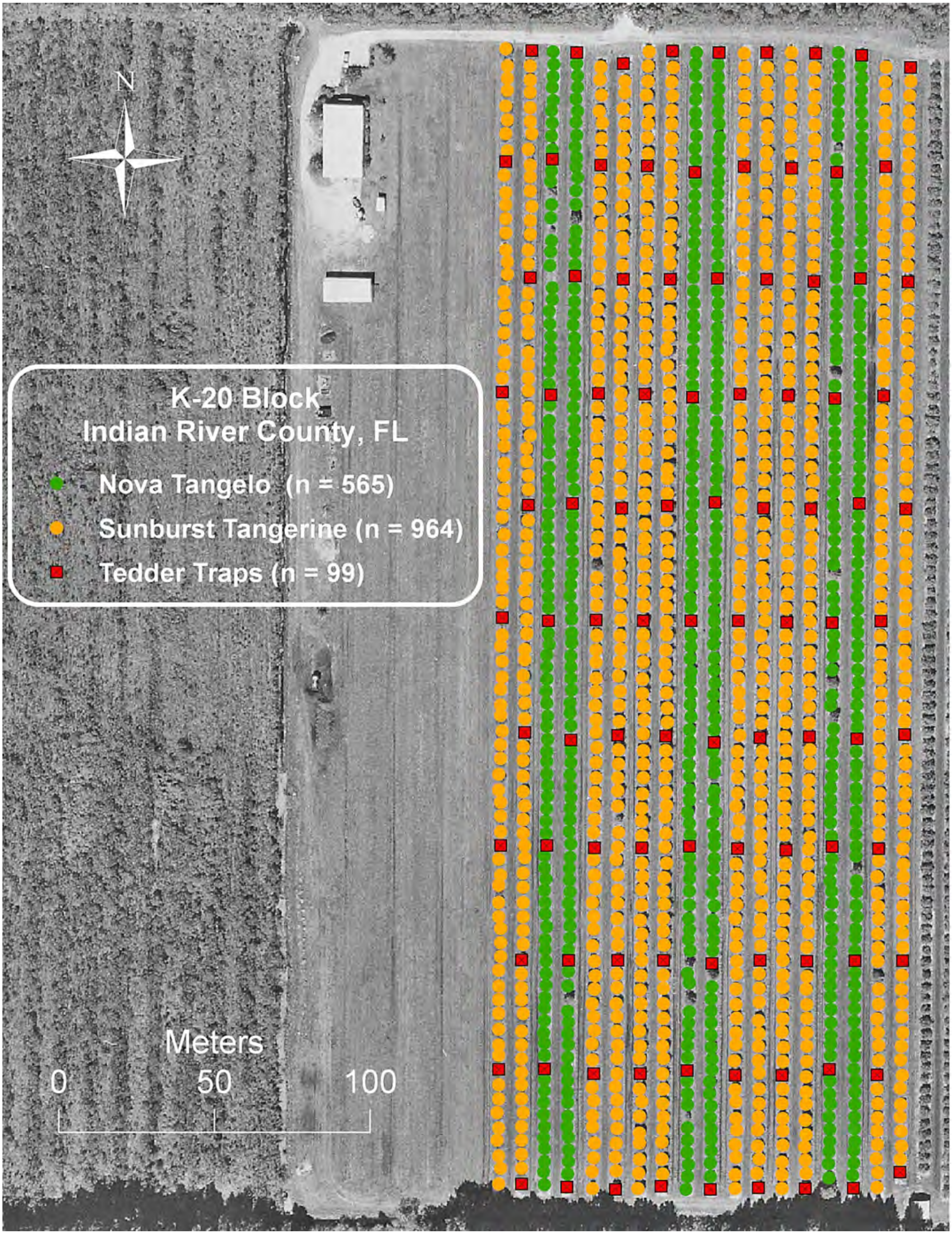

Fig. 1. Aerial overview of the 12.5 acre K-20 study site. Locations of Tedders Traps and tree varieties are represented by colored symbols and overlaid on a high resolution geo-referenced image.

Results and Discussion

Based on prior work comparing weevil collection methods (beating, cone traps, and Tedders Traps) with frass color where dark colored frass indicated leaf feeding and white frass indicated root feeding, adult *D. abbreviatus* captured by Tedders Traps can be considered as recently emerged adults from the soil (R. Adair and G. Dennis, Florida Research Center, personal communication). Therefore, adults captured by Tedders traps were considered as a measure of emergence. The *D. abbreviatus* emergence data from 28 Feb. 2000 through 29 Dec. 2003 was graphed annually (Fig. 2). In 2002, the greatest peak emergence occurred in February-March with the single largest mean number of adult weevils trapped per trap per week (1.23 ± 0.14 S.E.) during the entire study period. The greatest number of total weevils trapped per year also occurred in 2002. Other significant emergence peaks were observed in January 2002 and 2003, June 2000 and 2002, and Apr. 2001. The seasonal timing of the peaks and their duration during the year were derived from the line graphs. Previous investigators frequently reported peak emergence occurring during the spring, which was not consistent with all of our data. Peak emergence in 2000 was observed during a 3 week period in June with 126 *D. abbreviatus* captured resulting in 10.6% of the 2000 year total. We observed a 4 week period during April of 2001 that resulted in 20.4% of the yearly total captured. Weevil activity in 2002 produced a larger 6 week peak emergence period from February to March which resulted in 38.3% of the yearly total captured. The peak in 2003 consisted of 4 weeks during January and resulted in 30.3% of yearly total captured. Such temporal peaks and distributions can be established from the line graphs but the geographical location and duration of these periods of emergence within the grove cannot be established without further visualization techniques. Based on the temporal variation of emergence from year to year, scouting or trap monitoring would have to be performed for effective application of adulticides. No indication of where the high or low populations of *D. abbreviatus* can be derived from this type of temporal or seasonal data.

In addition to the basic line graphs, annual total *D. abbreviatus* distribution maps depicting emergence patterns were produced through the GIS for the same time period using color to indicate weevil density (Fig. 3). Such maps give a generalized geographical but temporally limited visualization of *D. abbreviatus* population distributions throughout the citrus grove on a yearly basis. Accordingly, greater emergence of *D. abbreviatus* is evident in years 2000 and 2002 by this same depiction and is similarly revealed by the line graphs. In contrast, the degree of emergence evident in 2001 and 2003 were smaller quantitatively and spatially. Of particular interest is the similar pattern of emergence of *D. abbreviatus* in the same geographical areas for all four years. Recurring populations can be seen in the northwest, southwest, and southeastern corners of the citrus grove. Such recurrent distributions are

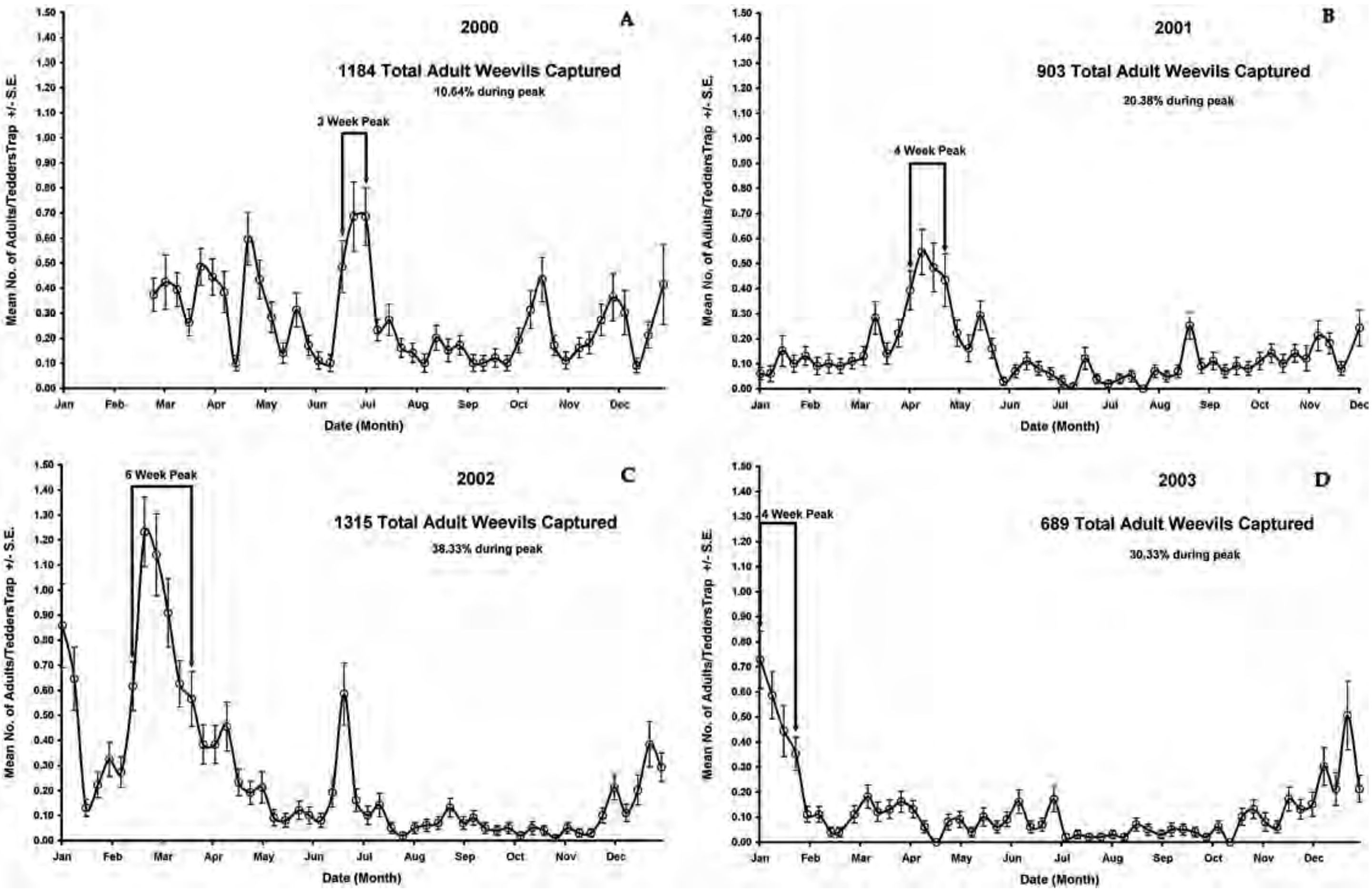

Fig. 2. Individual yearly graphs depicting the mean number of adult *D. abbreviatus* per Tedders Trap (n = 99) captured weekly for years 2000, 2001, 2002, and 2003 at the K-20 study site.

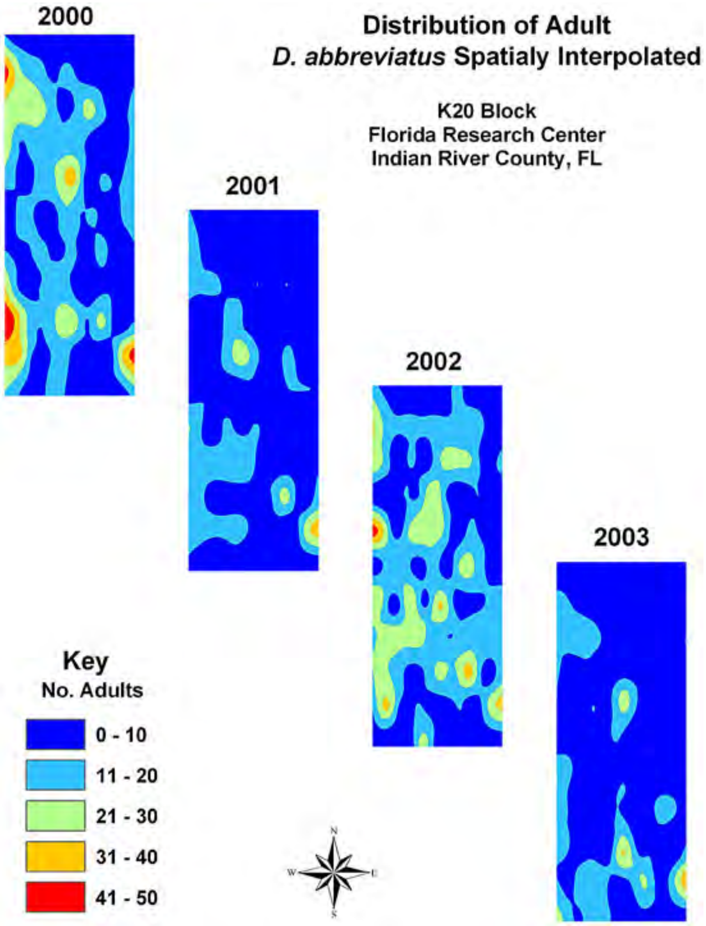

Fig. 3. Interpolated annual distribution maps depicting the annual *D. abbreviatus* spatial emergence patterns for years 2000, 2001, 2002, and 2003.

consistent with the areas where the initial invasion was suspected to have occurred (Adair et al., 2000) implying that weevil populations remain in place. When distribution patterns are used in conjunction with the line graphs in Fig. 2, a general indication of seasonal emergence locations begins to become apparent. However, to achieve the level of monitoring needed for a precision application for adult *D. abbreviatus*, one would require distribution maps to be produced for every week of the year. Visualization of this type of data needs to be improved to provide better real-time analysis of *D. abbreviatus* spatiotemporal aspects to ensure successful IPM program.

To provide such visualization for improved IPM, we have modified and further developed a real-time spatiotemporal visualization tool that incorporates a GIS and animation software for analysis of dynamic *D. abbreviatus* distribution patterns within a citrus block. Prior work by C. R. Rutledge-Connelly (Rutledge-Connelly et al., 2006) on West Nile Virus was expanded to include *D. abbreviatus* (Fig. 4). The visualization tool allows for temporal alignment of weekly *D. abbreviatus* distribution patterns with a graph depicting the total number of *D. abbreviatus* weevils captured during the same period. Temporal alignment of emergence patterns can be synchronized with recorded environmental conditions, such as rainfall, and incorporated into the animations. One of the main failures of static abundance maps is the obscurance of remarkable patterns by baseline or background activity. Since *D. abbreviatus* adult emergence patterns tend to follow seasonal, crop growth, and / or environmental patterns, it is important to differentiate between normal background distribution patterns of *D. abbreviatus* and the predominant emergence patterns. Our animation provides this by eliminating *D. abbreviatus* emergence background noise as discussed earlier since only "hot spots" are visualized in the animation. Also incorporated was the ability to scroll through the series of images temporally by use of a control slider located at the bottom of the animation, to allow for better analysis and inspection of the visualized data.

Each image shown in Fig. 4 is a 'still-shot' from the weekly animations timed at the peak weekly adult emergence for that listed year. Comparison of the images conveys that such distribution patterns are not discrete points in geographic space, but are continuous dynamic surfaces that coincide temporally with opportune environmental factors in that same geographic space. Temporally, these continuous surfaces may coincide, or even follow environmental factors such as soil type in time. Most interesting is the ability to recognize that peak *D. abbreviatus* emergence varies from year to year temporally and quantitatively while remaining fairly consistent geographically. Peak emergence for 2000 occurred in June, at the beginning of summer. Peak spring emergence occurred in both 2001 and 2002, in months February and April respectively. The peak emergence in 2003 occurred, oddly, in January, with no secondary abundance peak until December. Such differences may be due to any number of factors. Without visualization of such differences, deciding on which factor to base further research can be confounding.

Weekly *D. abbreviatus* survey data can be animated, which shows their movement through time and space more clearly than is possible using static maps and graphs. Our full-color Macromedia Flash video shows the spatiotemporal variation in weevil distribution using a series of interpolated maps. This way, viewers fully appreciate the ecology of *D. abbreviatus* and the factors that influence its distribution and development. For example, higher weevil populations appearing in the northwestern and southeastern sections of the grove show up in our animation as an explosion of color and intensity compared to other areas of the animation. Temporarily high populations occurring throughout the year in different areas of the grove also appear, but color patterns in the animation clearly show that weevils were more abundant during the fall and within 2 weeks after major rainfall events. Our animation also shows that environmental conditions such as rainfall and physical parameters (e.g., soil texture soil and EM38 electrical conductivity) may be conducive or restrictive to weevil development.

Animation analysis shows that the detection of high weevil populations early in the year may not warrant the same level of response as finding the same number of weevils in the same geographic position later that same year. Further, some crop managers may act based solely on high weevil populations that coincide with certain soil and environmental conditions. Other crop managers may react differently to the same level of weevil activity based more on spatiotemporal aspects. The accurate interpretation of dynamic weevil cycles requires the simultaneous analysis of different levels of information, but traditional static maps have limitations that can be circumvented using animation. Ecological conditions (e.g., soil type and weather events) also have to be considered. The level of work involved in coordinating and aligning these many information resources just does not permit rapid analysis and reporting of multi-factored pest survey results. Nevertheless,

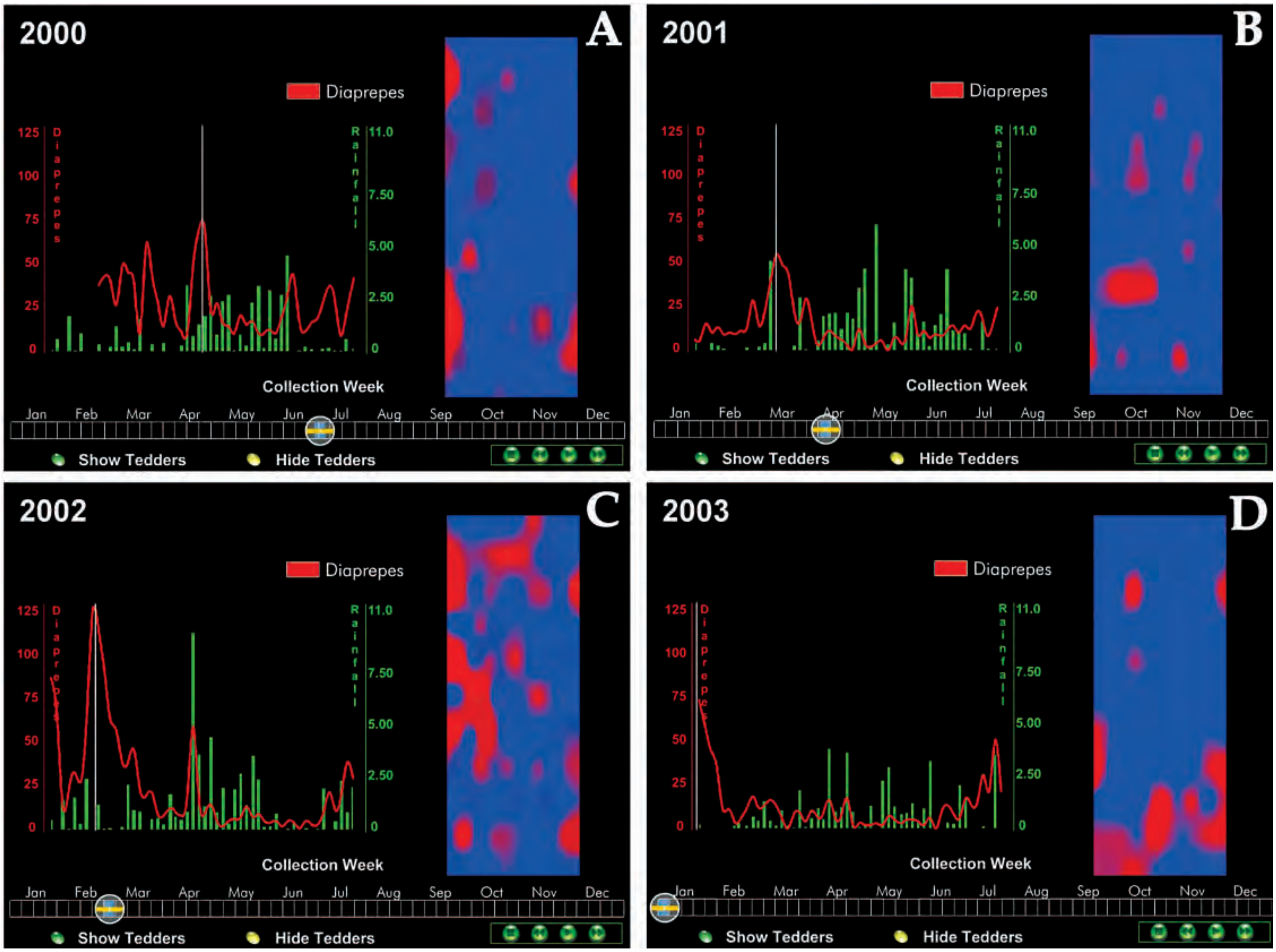

Fig. 4. Combined view of emergence/rainfall graph with still-shot images of spatial animation videos comparing the peak weekly *D. abbreviatus* emergence patterns (in red) for each of the 4 years (2000 to 2003) at the K-20 study site. Click on the link (or visit: http://www.fshs.org/Proceedings/2006-Vol.%20119/Fig-4A.EXE; http://www.fshs.org/Proceedings/2006-Vol.%20119/Fig-4B.EXE; http://www.fshs.org/Proceedings/2006-Vol.%20119/Fig-4C.EXE; http://www.fshs.org/Proceedings/2006-Vol.%20119/Fig-4D.EXE) for time-lapse spatiotemporal animation of the data.

our Flash animation successfully achieved the geographical and temporal alignments required to clearly envision *D. abbreviatus* distribution and movement in a citrus grove.

The purpose of the animation is to emphasize that *D. abbreviatus* survey data should be reported in real-time. This is because critical management responses should be coordinated to the spatial and temporal distribution of weevils within a particular citrus grove. Crop-pest interactions are spatially and temporally dynamic and we demonstrated that animation is a powerful tool for representing this type of information (Blok, 1999). Further work will be directed to ways in which animation analysis can be provided in real-time as a service to the industry.

Literature Cited

Adair, R. C., Jr., N. K. Mehta, and J. H. Graham. 2000. A pilot study on the spatial distribution of *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae) and *Phytophthora* spp. Proc. Fla. State Hort. Soc. 113:82-88.

Blok, C., B. Kobben, T. Cheng, and A. Kuterema. 1999. Visualization of Relationships Between Spatial Patterns in Time by Cartographic Animation. Cartography and Geographic Information Sci. 26(2):139-151.

Duncan, L. W., C. W. McCoy, P. A. Stansly, J. H. Graham, and R. F. Mizell. 2001. Estimating the relative abundance of adult citrus root weevils (Coleoptera: Curculionidae) with modified Tedders traps. Environ. Entomol. 30:939-946.

Graham, J. H., C. W. McCoy, and J. S. Rogers. 1997. The *Phytophthora-Diaprepes* weevil complex. Citrus Ind. 78(8):67-70.

Hall, D. G. 1995. A revision to the bibliography of the sugarcane rootstalk borer weevil, *Diaprepes abbreviatus* (Coleoptera: Curculionidae). Fla. Entomol. 78:364-377.

Hall, D. G. 2000. History and importance of Diaprepes to Florida, pp. 13-16. In: S. H. Futch, (ed.) Diaprepes Short Course. IFAS Coop. Ext. Serv. Lake Alfred, FL.

Hofierka J., J. Parajka, H. Mitasove, and L. Mitas. 2002. Multivariate Interpolation of Precipitation Using Regularized Spline with Tension. Transactions in GIS. 6(2):135-150.

Knapp, J. L., H. N. Nigg, S. E. Simpson, L. W. Duncan, J. H. Graham, J. E. Peña, C. W. McCoy, and C. M. Mannion. 2001. Diaprepes Root Weevil: A Pest of Citrus, Ornamentals, and Root Crops in Florida. Fla. Coop. Ext. Serv. Cir. ENY-645.

Li, H., J. P. Syvertsen, R. J. Stuart, C. W. McCoy, A. W. Schumann, and W. S. Castle. 2003. Correlation of Soil Characteristics and *Diaprepes abbreviatus* Root Weevil Populations in a Poorly Drained Citrus Grove. Proc. Fla. State Hort. Soc. 116: 242-248.

McCoy, C. W. 1999. Arthropod pests of citrus roots, pp. 149-156. In: L. S. Timmer and L. W. Duncan (eds.). Citrus health management. Amer. Phytopathol. Soc., St. Paul, MN.

McCoy C. W. and L. W. Duncan. 2000. IPM: An emerging strategy for Diaprepes in Florida citrus, pp. 90-104. In: S. H. Futch (ed.). Diaprepes Short Course. IFAS Coop. Ext. Serv. Lake Alfred, FL.

McCoy C. W., R. J. Stuart, and H. N. Nigg. 2003. Seasonal life stage abundance of *Diaprepes abbreviatus* in irrigated and non-irrigated citrus plantings in Central Florida. Fla. Entomol. 86(1):34-42.

McCoy, J. and K. Johnston. 2001. Using ArcGIS Spatial Analyst. ESRI Press, Redlands, CA.

Rutledge-Connelly, C. R., J. F. Day, and G. K. Ross. 2006. Enhancing Mosquito-Borne Disease Surveillance in Florida. J. of Ext. (In press).

Simpson, S. E., H. N. Nigg, N. C. Coile, and R. C. Adair. 1996. *Diaprepes abbreviatus* (Coleoptera: Curculionidae): host plant associations. Environ. Entomol. 25:333-349.

Woodruff, R. E. 1964. A Puerto Rican weevil new to the United States (Coleoptera: Curculionidae). Fla. Dept. Agr. Div. Plant Ind. Entomol. Cir. 30:1-2.