NEWA (Network for Environment and Weather Applications) Provides Fruit IPM and Production Tools from 400 Weather Stations

Juliet Carroll[1], Tim Weigle[2], Art Agnello[3], Harvey Reissig[3], Kerik Cox[4], Deborah Breth[5], Terence Robinson[6], Greg Loeb[3], Wayne Wilcox[4], Keith Eggleston[7], Art DeGaetano[7], Dan Olmstead[1], Jennifer Grant[1], John Gibbons[1,8], and Curt Petzoldt[1]

[1]New York State Integrated Pest Management Program, Cornell Cooperative Extension, Geneva, NY
[2]New York State Integrated Pest Management Program, Cornell Cooperative Extension, Portland, NY
[3]Department of Entomology, Cornell University, NYSAES, Geneva, NY
[4]Plant Pathology and Plant-Microbe Biology Section, School of Integrative Plant Sciences, Cornell University, NYSAES, Geneva, NY
[5]Lake Ontario Fruit Program, Cornell Cooperative Extension, Albion, NY
[6]Horticulture Section, School of Integrative Plant Sciences, Cornell University, NYSAES, Geneva, NY
[7]Northeast Regional Climate Center, Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY
[8]Ontario County Cornell Cooperative Extension, Canandaigua, NY

This work was partially supported by the Apple Research and Development Program and the New York State Berry Growers Association.

The Network for Environment and Weather Applications (NEWA) provides web-based apps supporting digital agriculture at http://newa.cornell.edu/. The tools on NEWA give open-access, real time decision support to end users for integrated pest management (IPM) and crop production. NEWA builds tools from plant phenology, insect phenology, and plant disease epidemiology models land grant university researchers have developed by correlating weather data to plant and pest development in laboratory, growth chamber, greenhouse and field experiments. Field validation occurs before implementation into NEWA tools that include the current, historic, and 5-day forecast outlook. Today, over 40 tools in NEWA, from growing degree days to apple thinning, support agriculturally relevant decisions on the farm. We are pleased to announce a full time NEWA coordinator in the New York State IPM Program, Dan Olmstead (dlo6@cornell.edu), who started in January 2017.

> **"NEWA has a proven track record for providing grower benefits and outcomes that include improved IPM practice, reduced environmental impact, and improved crop yield and quality."**

History. In 1996, NEWA started in NY with about 40 weather stations supported by the NYS IPM Program. As of 2017, NEWA serves 12 member states with five additional farms in outlying states (Figure 1). Land grant universities and apple grower associations in North Carolina and Minnesota partner with NEWA (Figure 2) and each state designates a NEWA coordinator to manage their network. Since 2008, the Northeast Regional Climate Center (NRCC) has provided database, programming, and meteorological expertise. In 2016, over 400 weather stations (150 in NY) were included in NEWA's network and with the addition of the Michigan mesonet, there will be

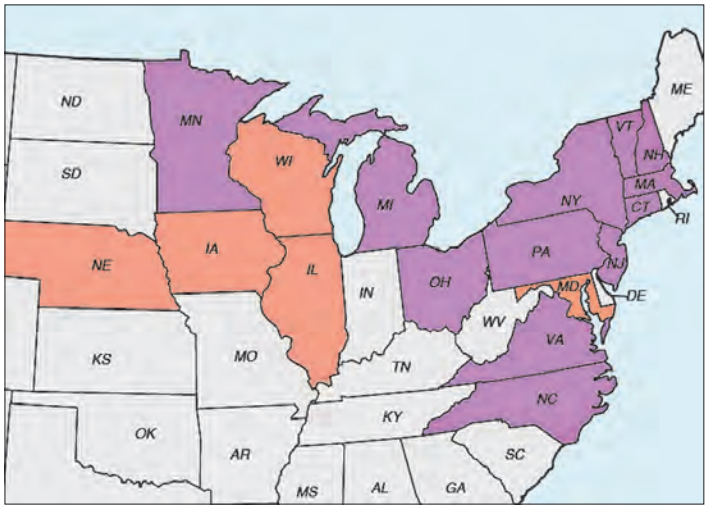

Figure 1. Map showing NEWA member states (purple) and outlying states (orange) with individual farm members. Michigan and Ohio partnerships began in 2017.

Figure 2. NEWA partner institutions and associations.

over 500 in 2017. Producers host most weather stations in NEWA, which uses Rainwise AgroMet weather stations. The State Climatologists in New Jersey at Rutgers and in Michigan at Michigan State University maintain independent mesonets in their states, providing those data to NEWA. Michigan has Enviro-Weather, which is a similar system to NEWA. National Weather Service (NWS) stations, provided through the NRCC and served on NEWA, show as airport icons on the map. These data have a relative humidity correction factor and leaf wetness data based on a humidity threshold (Table 1).

Table 1. Comparison of five models to estimate leaf wetness. Best estimates have "fraction of correct estimates" closest to one; "correct success index" closest to one; "false alarm ratio" closest to zero. The "bias" measure < 1 is an underestimate and > 1 is an overestimate. Highlighted in dark blue are the best estimate scores, in brown the worst. NEWA uses an average RH ≥ 90% to estimate an hour of leaf wetness.

Estimate Scores for Leaf Wetness Models vs. Observed Leaf Wetness*				
Leaf Wetness Model	Fraction of Correct Estimates	Correct Success Index	False Alarm Ratio	Bias
Fuzzy Logic [a]	0.730	0.247	0.533	0.736
CART [b]	0.711	0.388	0.540	1.550
Dew Point Depression [c]	0.746	0.417	0.506	1.469
Extended RH [d]	0.656	0.355	0.600	1.894
RH ≥ 90% [e]	0.756	0.420	0.491	1.385

*Observed leaf wetness threshold for 1 hour wet used in NEWA plant disease tools is ≥ 1 min/hr
[a] Fuzzy Logic Decision Tree (temperature, RH, wind speed, time of day)
[b] CART (Classification and Regression Tree) model (temperature, RH, wind speed, time of day)
[c] Dew Point Depression threshold (wet if ≤ 1.8C; dry-off if ≥ 2.2C)
[d] Extended RH threshold (wet if RH ≥ 87%; dry-off if ≤ 70%; dry-off if RH decreases more than 4% in an hour)
[e] RH threshold (≥ 90%)

Fruit tools. Many tools in NEWA address apple and grape decision support. Fourteen for apples (fire blight, apple scab, sooty blotch & flyspeck, spotted tentiform leafminer, oriental fruit moth, codling moth, plum curculio, obliquebanded leafroller, apple maggot, San Jose scale, apple carbohydrate thinning, apple irrigation, apple evapotranspiration, and apple frost risk) and five for grapes (Phomopsis cane and leaf spot, powdery mildew, black rot, downy mildew, and grape berry moth). Over the next year, we will develop and validate eight tools for berry crops (strawberry and blueberry gray mold, strawberry and blueberry anthracnose, mummyberry, cranberry fruitworm, blueberry maggot, and strawberry root weevil), readying these for full implementation in 2018. In addition, eNEWA for grapes, a daily email sent to subscribers, provides a summary of grape tool results. An apple eNEWA, successfully beta tested, requires further development. A data product developed in 2016 sends station weather data from NEWA into RIMpro, a third party software program purchased separately, which has an apple scab simulation model among other tools.

Outreach & Impact. NEWA is the topic of many presentations and workshops throughout the coverage areas. For instance, 22 presentations and workshops tracked by the NYS IPM Program in 2015 reached over 1300 people. The results from NEWA's tools frequently appear as topics in extension newsletters with regional and statewide reach, informing producers about upcoming risks and the potential need for intervention to protect or grow the crop. In recent years, NEWA's website has enjoyed over 1.5 million page views per year (defined as when the user spends at least a half hour on the page). NEWA also supports field research and secondary and undergraduate education.

NEWA significantly improves IPM practice and adoption. In a survey of primarily apple and grape growers using NEWA, given in 2007 before the current website launched, the majority agreed that NEWA improved their IPM practices (Figure 3) and 99.2% of NEWA users said they would recommend NEWA to farmers. In a recent stakeholder evaluation of the University of Vermont's outreach programming, 93% of growers identified access to NEWA as beneficial to their pest management programs, with 86% indicating a decrease in pesticide use and 71% reporting increased profitability resulting from use of NEWA (T. Bradshaw, personal communication). Some representative grower comments about NEWA: "The orchard was largely scab-free for the first time in several years. The orchard manager depended heavily on NEWA and could see significant differences between the on-site station and the one we had been using"; and "I use the NEWA site almost every day early in the season."

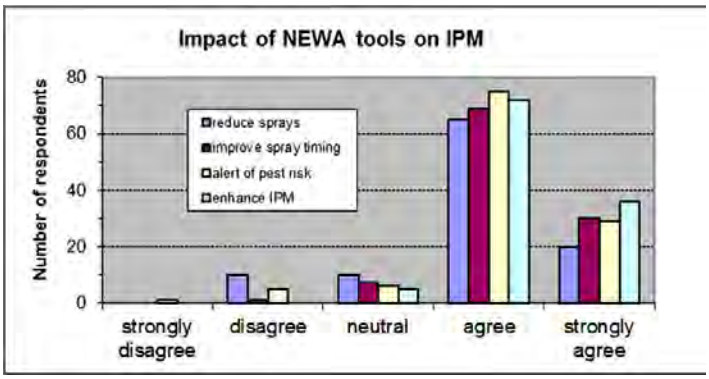

Figure 3. NEWA has positive impact on farm IPM practices as evaluated by The Survey Research Institute (SRI), Cornell University in 2007. This was before our current, app-based, website launch in 2009.

Skill in Weather Station Maintenance

In NY, about a fifth of all weather stations are on apple farms. To improve the accuracy and reliability of the weather stations in NY NEWA, we investigated the status of the majority of weather stations located on apple farms. This project contributed significantly to the reliability and accuracy of the weather station data by building grower expertise.

We exceeded our target by 33%, reaching 32 apple farmers in NY who own NEWA weather stations and performing field analyses. Owners and farm managers learned about station maintenance and calibration methods during field visits. Field visit analyses on 32 of the 38 Rainwise weather stations located on NY apple farms skipped two that were no longer connected to the network, two maintained by NEWA, and two on Long Island, outside the reach of the project. Based on analysis of the data reported on the NEWA website, we determined that 18 of the 32 instruments were not working correctly before the field visit: 10 with relative humidity (RH) sensor errors, 2 with rain gauge problems, and 11 with data transmission outages. Nine of the 18 stations were repaired either during the field visit or afterwards by the grower. Six needed the RH sensor replaced. Three had data transmission problems – one needed relocation, one went back to RainWise due to a short circuit in the wiring, and one needed a new receiving base.

Prior to farm visits, we wrote a Troubleshooting and Maintenance Guide, distributed during field visits. A blog, *You're NEWA*, blogs.cornell.edu/yourenewa/, was created, and all NEWA contacts

subscribed to it. Several blog posts covered troubleshooting and maintenance, pointing to the troubleshooting and maintenance guides. The NEWA website now points to the guides in the main menu, under **About Weather Stations:**

- **Maintenance Guidelines** newa.cornell.edu/index.php?page=maintenance-guidelines
- **Troubleshooting Guide** newa.cornell.edu/index.php?page=weather-station-troubleshooting-guide.

Two workshops on weather station maintenance, troubleshooting and calibration techniques, *Improving the Reliability of your Weather Station*, were held in February 2015 in Geneva and Highland, NY. An actual weather station for hands-on use allowed attendees to learn how to troubleshoot weather station issues. Rainwise Inc., the weather station manufacturer, participated via Skype link during a question and answer segment. Based on Qualtrics survey evaluations, the workshops were successful in informing attendees about weather station maintenance and troubleshooting. In Geneva, 21 attended, and 9 in Highland. Eighteen (60%) responded to the workshop evaluation. We found considerable change in knowledge after the workshop. Most attendees were already planning how to utilize the information they had learned about weather stations. After attending the workshop, participants are now doing the following:

- (84%) Routinely, at least once per year, clean the rain gauge, inspect all sensors and connections on the weather instrument and on the IP-100.
- (72%) Periodically check the weather station battery voltage on RainwiseNet.
- (56%) Check weather data on RainwiseNet and NEWA for data gaps.
- (56%) Have the weather station calibrated by Rainwise every two years.

One person reported that the 2015 season had the best weather station performance in the Wayne County area they had seen, underscoring the value of routine maintenance.

Favorite portions of the workshop were the Skype session with Rainwise Tech Support; the slide presentation about common maintenance issues, data transmission, and RainwiseNet settings; and the demonstration of dismantling the weather station. Based on requests from attendees, two workshops during the 2016 Hudson Valley Winter Fruit School gave attending apple and grape growers the opportunity to learn about using NEWA's tools. Presentations and hands-on demos on NEWA were given at New York State Berry Growers Association-sponsored Workshops in January and February 2017.

New tools and upgrades

As with weather stations, improving the accuracy and user experience of the models on NEWA is a priority. One top priority was to reinstate the degree day calculator in 2016. We implemented improvements to the apple tools on NEWA. We built forecasts into six apple insect tools for enhanced decision support. A new tool for the emergent pest, San Jose scale, was also implemented in NEWA in 2016.

The NEWA Degree Day Calculator, newa.cornell.edu/index.php?page=degree-day-calculator, provides an easy way to calculate the accumulated degree days for a desired date range for any base temperature used in NEWA tools. The results show the degree day value for each day in the 5-day forecast window and a chart of degree day progression for the chosen date range, which includes the forecasted data. This degree day calculator allows apple growers and others to determine specific degree day accumulations between dates of their choosing (Figure 4).

We improved the apple insect tools in NEWA that inform IPM intervention for codling moth, oriental fruit moth, oblique-banded leafroller, plum curculio, spotted tentiform leafminer, and apple maggot, improving these with degree day forecasts for five days into the future. The insect tools now include a table of the insect's daily degree day accumulation that is forecasted for its developmental base temperature five days into the future. Enhanced IPM messages accompany the new forecast-inclusive apple insect tools. These improvements allow end users to know if IPM action thresholds for key insect pests are looming and to take steps to prepare for suggested management tactics.

The new tool for San Jose scale operates similarly, with forecasts and graphs charting the insect's developmental degree day accumulations (Figure 5). All NEWA tools have an easy-to-use selection dashboard on the left with results displayed on the right. These insect tools' results have location-specific, real time estimates for insect development status with appropriate IPM messages that change as the degree days accumulate from biofix. The improved and new apple insect tools are now available at newa.cornell.edu/index.php?page=apple-insects; easily accessed from the NEWA main menu under **Pest Forecasts/ Apple Insects**.

Future directions

NEWA's end users and state coordinators provide guidance and advice on future development. Grower-based support of NEWA continues to increase, with new weather stations being added routinely. A grower cache for crop growth stage and first trap catch dates to inform the model biofix (start date) would enhance user experience. Virtual stations built from the NWS gridded forecast database could create station locations anywhere on the map. A developer sandbox would revolutionize the ability of scientists to create, validate, and implement new tools in NEWA. These are just a few of the ideas put forth by our stakeholders. Our new partner states, Ohio and Michigan, and our nascent collaboration with the NYS Mesonet will bring more minds to the table for advances in digital agriculture applications that will benefit producers.

New tools. While not new, the apple scab and fire blight tools need enhancements. Calculating ascospore depletion with the apple scab tool will improve the estimation of the end of the primary scab season. The epiphytic infection potential algorithm from Maryblyt software, courtesy of developer Alan Biggs, will be woven into the fabric of the fire blight tool along with humidity forecasts, an improved user interface and disease management messages. We plan to refine the apple phenology calculations for use in all the apple tools, and ultimately implement a green tip date predictor. Eight tools for berry crops are slated for full implementation in 2018, following validation in 2017. Our partners to the south have requested tools for tufted apple bud moth, brown marmorated stink bug, oriental fruit moth in peaches, and bacterial spot of peach. An additional model for apple thinning, the pollen tube growth model, would provide thinning options for organic production.

Development. Look for our NEWA survey, which will inform a ten-year perspective on NEWA, its impact on agriculture and requirements for a successful future. The website will become

mobile-friendly, working on a smart phone more like an app than a website. NEWA's stakeholders will contribute ideas for this vision in a technology strategy workshop in 2017. Along with the responsive website will be development of virtual weather stations, growers' cache, and a premium interface. With more than forty models on our current wish list, from sectors as diverse as Christmas trees and dairy farms, the future demands a developer sandbox just to keep pace.

New partnerships. The strength of NEWA is its partnerships. We will embark on a collaboration with the NYS Mesonet, a network of 125 state-of-the-art weather stations built by the University at Albany to inform NY citizens about weather as our climate becomes more volatile and weather events extreme. The Ohio State University (OSU) and the USDA Agricultural Research Service at The OSU look forward to building a NEWA network in Ohio where extension scientists will work primarily with apple and grape growers. Our partnership with Michigan and the Enviro-Weather network was sparked by their interest in the Cornell apple irrigation and Cornell apple carbohydrate thinning tools. This partnership bodes well for a future where NEWA and Enviro-Weather build ever greater excellence in digital agriculture.

NEWA, newa.cornell.edu, has a proven track record for providing grower benefits and outcomes that include improved IPM practice, reduced environmental impact, and improved crop yield and quality. This is particularly true for apple production, as there are now 14 apple-specific IPM and crop production forecast models implemented in NEWA. Our ARDP-funded project built grower expertise in weather station maintenance for NEWA and achieved improvements to the apple insect and degree day tools on NEWA. These outcomes will ultimately contribute to the economic success and IPM practices of apple growers using the NEWA tools.

Literature cited

Bishop, B. 2014. Enviro-weather: Online weather-based information to aid in good decision-making. NYFQ 22(4): 25–29.

Carroll, J., Weigle, T., Seaman, A., and Grant, J. 2016. NEWA (Network for Environment and Weather Applications) 2015: a year in review. NYS IPM Program Report, Cornell Univ. 7 pp. newa.cornell.edu/uploads/IPM_NEWA_Report_2015final.pdf. Accessed 1/23/2017.

Mague, D. L., and Reissig, W. H. 1983. Phenology of the San Jose scale (Homoptera: Diaspididae) in New York State apple orchards. Can. Entomol. 115: 717–722.

Acknowledgements

Crowd-sourced, open access NEWA can't exist without the

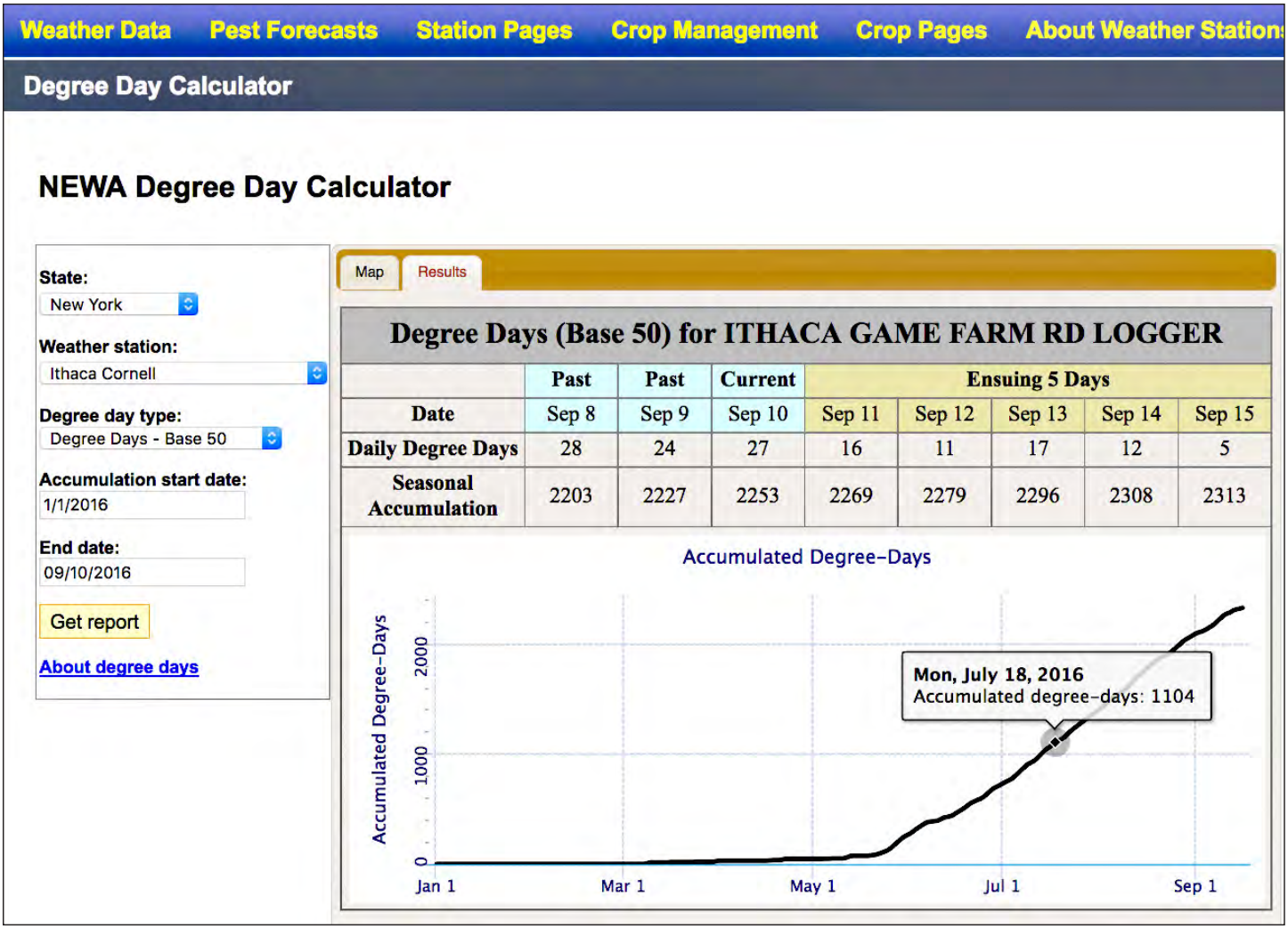

Figure 4. NEWA's degree day calculator gives location-specific degree day accumulations for several base temperatures. Choose a date range and results show in a table and chart. Scroll over the line to get specific degree days for each point.

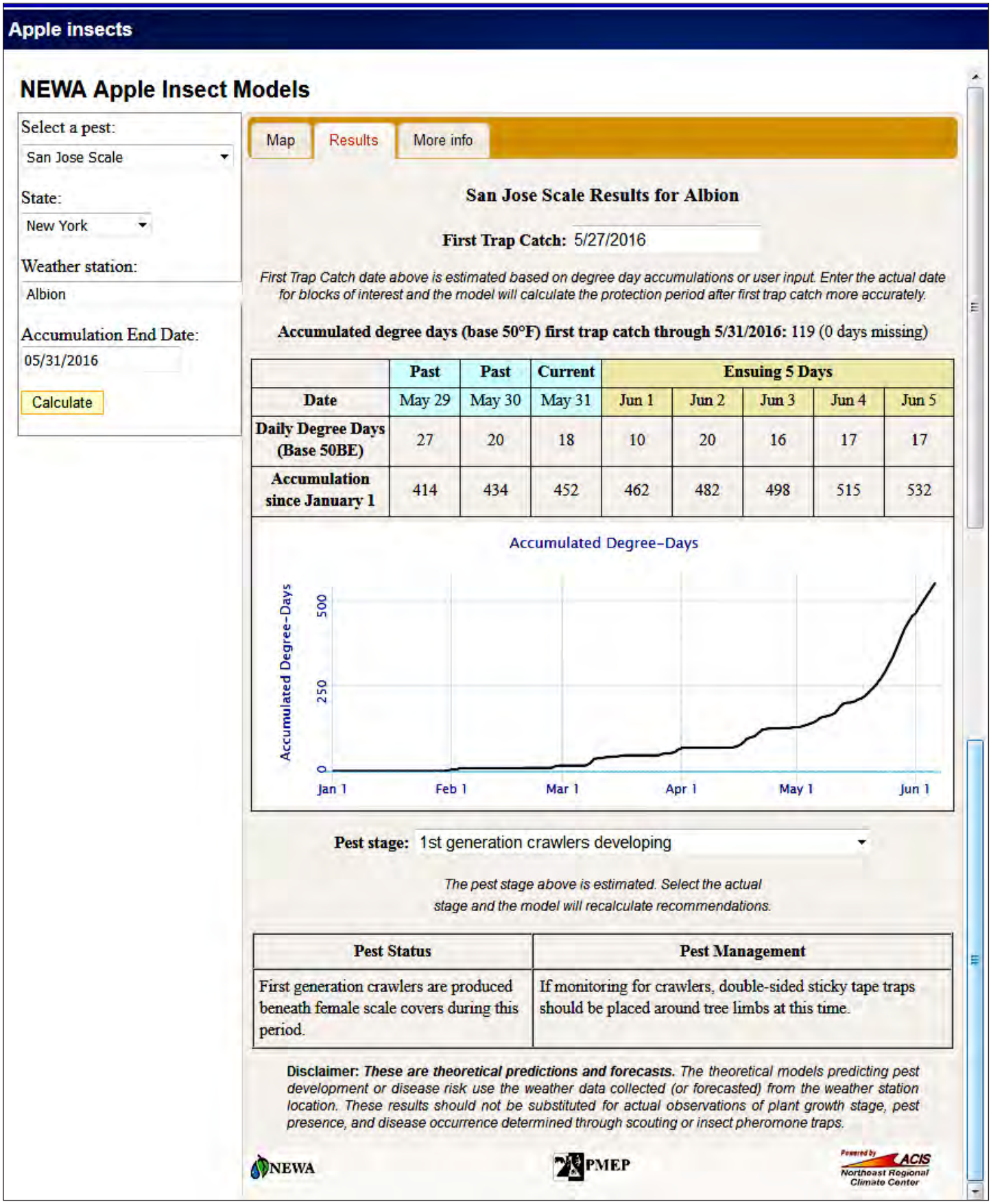

Figure 5. The San Jose scale tool in NEWA is typical of the apple insect tools and many other insect tools in NEWA. Degree days are tabulated and a chart is generated showing degree day accumulations. Below the table and chart, messages about pest status and pest management specific to the pest, date and location of interest inform the end user. New in 2016, the apple insect tools include forecasted degree days in the results.

shoulders of many to stand on. The authors would very much like to acknowledge the support of growers, extension faculty, educators, programmers, researchers and professors across the Northeast, Southeast and Midwest who are too numerous to mention by name. We want to especially acknowledge our state coordinators, essential to NEWA's growth and impact: Terence Bradshaw, University of Vermont; Jon Clements, University of Massachusetts Extension; Peter Oudemans, Rutgers The State University; Robert Crassweller, Pennsylvania State University; Mary Concklin, University of Connecticut; JP Jacobson, Pine Tree Apple Orchard, Minnesota Apple Growers Association; Michael Parker, North Carolina State University; Cheryl A. Smith, University of New Hampshire Extension; Mizuho Nita, Virginia Polytechnic Institute and State University; Matthew Wallhead, USDA-ARS-ATRU, The Ohio State University; Beth Bishop, Michigan State University.

Juliet Carroll has led the New York State IPM Program's weather network, NEWA, the Network for Environment & Weather Applications, since 2005. She is the Fruit IPM Coordinator for the New York State IPM Program at Cornell University. Julie recognizes the importance of weather in driving disease and insect development in orchards and vineyards. She and colleagues in the New York State IPM Program and the Northeast Regional Climate Center have developed NEWA into a user-friendly suite of apps to assist growers in their IPM and crop management decisions.