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Monitoring the Spatial Distribution of Pests Growth in Iraq Using Spatial Analysis and Degree Days Models

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ABSTRACT

In this paper, we present a computerized system to monitor the growth of pests in Iraq by proposing a web based system integrating Google maps with mathematical models to generate simultaneous maps to enable agriculture scientists and farmers to have insight about the growth of pests in their regions. The inverse distance weighting technique used to estimate temperature data of each point locations in the surface. Single sine model is applied to estimate degree days due to its practicality in providing a better predictive capability. The results of the system viewed online on digital maps with a spatial resolution 200km*200km.

الخلاصة

في هذا البحث تم اقتراح نظام شبكي محوسب لمراقبة نمو الافات الزراعية في العراق متكامل مع خرائط كوكل ونماذج رياضية لتوليد خرائط انية تمكن الباحثين الزراعيين والمزارعين من مراقبة نمو الافات الزراعية في مناطقهم. استخدمت تقنية توزين المسافة المعكوسة لاستكمال بيانات الحرارة من محطات الطقس لكل موقع على سطح العراق. تم تطبيق نموذج الموجة المنفردة لتقدير الدرجات الحرارية من خلال فاعليتها في إعطاء تنبوء جيد لنمو الافة. نتائج النظام تم عرضها بشكل اني على خرائط رقمية وبدقة مكانية مقدارها 200×200 كيلومتر.

Keywords: Degree days, Pests growth maps, Google maps, spatial analysis, Iraq pests data

1. INTRODUCTION

The ability to monitor pests' growth and predict the emergence of them in different regions at the same time is fundamental to get an integrated pest management system.

In agriculture, the degree days have been widely used to quantify and predict pest's phonological events, and according to [10] and others it is more accurate than using chronological time or predicting events according to the season of the year. The degree days are implemented in several pests' phonology studies e.g. [8,2,3,14, 16, 1, 15, 25; 19].

In Iraq there is an urgent need to design a system works to predicate the growth of pests that harm the economical crops such as Dates. Dates are one of important crops in Iraq and have a significant effect on its economy. Date palms infected by many agriculture pests such as bugs, moths, and mites, which are the most important pests on date palms.

The growth of pests is influenced by weather, especially the temperature that is the most important variable, often has a large effect on pests' growth. The temperature data for pests forewarning systems is either directly observed or interpolated from a set of neighboring stations, then implementing the spatial analysis that play an important role in the integration of weather data in pests forewarning systems could have a crucial impact on the accuracy of prediction of pests activities. Several studies applied spatial interpolation techniques to estimate temperature data e.g. [21, 27, 6, 5].

Data visualization through maps becomes increasingly common and beneficial. Therefore, using web based GIS (Geographic Information System) mapping applications with pests forewarning systems plays a significant role in helping researchers and agricultural to monitor pests' growth in their areas through the web. Most web based GIS mapping applications are based on three GIS web based technologies to implement the visualization functionality: static renders maps, slippy maps, and flash mapping [13]. Each technology has its uses and choosing the appropriate technology is based on the time requirements that it takes for the user to execute a query and to receive the outcomes. Slippy maps are a geovisualization technique works by splitting the map into a discrete number of zoom levels. Each zoom level has a similar number of tiles. Tiles are served to users based on requests instead of serving the whole map immediately. Today, slippy maps are the most important and widely used technique where several products such as Yahoo maps, Google maps, and others are based on it.

2. MATERIALS AND METHODS

In this research, Phonological data of three pests are collected from studies applied in Iraq to be used in the proposed system [2, 23, 7] as described in Table (1).

Linear degree day models are mathematical models describe the rate of development for an organism to complete one of its life stages as a functional response which is dependent on temperature variables and two threshold parameters (upper and lower temperature thresholds). These models describe organisms development as a composite of time and temperature, measured as the cumulative sum of degree-time products, with daily time steps resulting in units of degree days. Linear degree day models are widely used due its practicality in providing a better predictive capability.

In this research, the single sine model [9] has been applied widely to predict pests' emergence e.g. [22, 20, 11, 4, 17].

Table (1): Sampled data for five pests collected from researches implemented in Iraq.

Common name	Scientific name	Phonological events								Biofix date
		Egg		Larvae		Pupae		Adult		
		L_{th}	DD	L_{th}	DD	L_{th}	DD	L_{th}	DD	
Dubas Bug	Ommatissus lybicus	12.15C	641.03	13.47C	515.56			13C	691.58	1 Jan
		U_{th} : 35C								
Batrachedra amydraula	Lepidoptra: Cosmopterygidae	14.61C	53.8					10.5C	625	1 Jan
		U_{th} : 35C								
Oligonychus afrasiaticus (McGregor)	Phoenix dactylifera L.	L_{th} : 13C, **DD** : 255.75								1 Jan
		U_{th} : 35C								
L_{th}: lower development threshold, **DD:** Average degree days; U_{th}: Upper development threshold, **C:** Celsius temperature unit.										

Single sine model uses daily minimum and maximum temperatures to produce a sine curve over 24 hour period, and then determines the amount of degree days for that day by calculating the amount of the area under the temperature curve and above the development threshold (base temperature) as shown in the Figure 1. The single sine model offers a better approximation of the curvilinear behavior of the temperature. The mathematical formulas of this model are showed in Table (2).

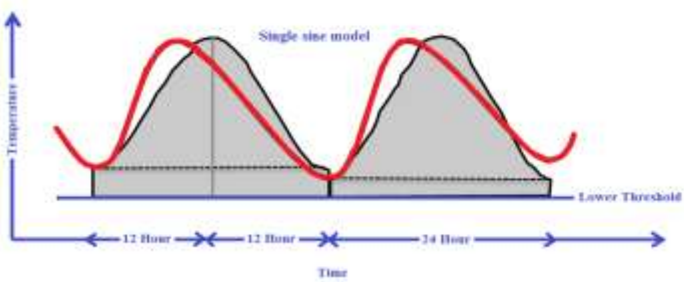

Figure 1. Single sine model, the plotted curve represents the temperature cycle over two days, while the area of the shaded region indicates the degree days that are accumulated.

Table (2): Formulas of the single sine model for calculating degree days (DD).

Temperature Situations	Equation
	$\alpha = (T_{max} - T_{min})/2$
	$\varnothing_1 = \sin^{-1}[[L_{th} - (T_{max} + T_{min})/2]/\alpha]$
	$\varnothing_2 = \sin^{-1}[[U_{th} - (T_{max} + T_{min})/2]/\alpha]$
$T_{min} > L_{th}$ & $T_{max} > U_{th}$	$DD = 1/\prod\{[(T_{max}+T_{min})/2 - L_{th}]*(\varnothing_2+\prod/2) + (U_{th} - L_{th})*(\prod/2 - \varnothing_2) - [\alpha*\cos(\varnothing_2)]\}$
$T_{min} < L_{th}$ & $T_{max} > U_{th}$	$DD = 1/\prod\{[(T_{max}+T_{min})/2 - L_{th}]*(\varnothing_2 - \varnothing_1) + \alpha*(\cos(\varnothing_1) - \cos(\varnothing_2)) + (U_{th} - L_{th}) * (\prod/2 - \varnothing_2)\}$
$T_{min} >= L_{th}$ & $T_{max} <= U_{th}$	$DD = (T_{max}+T_{min})/2 - L_{th}$
$T_{min} < L_{th}$ & $T_{max} < U_{th}$	$DD = 1/\prod\{[(T_{max}+T_{min})/2 - L_{th}]*(\prod/2 - \varnothing_1) + [\alpha*\cos(\varnothing_1)]\}$
$T_{min} > U_{th}$ & $T_{max} > U_{th}$	$DD = U_{th} - L_{th}$
$T_{min} < L_{th}$ & $T_{max} < L_{th}$	$DD = 0$

T_{max}: Maximum daily temperature; T_{min}: Minimum daily temperature; U_{th}: Upper temperature threshold; L_{th}: Lower temperature threshold.

In order to develop an adequate pests forewarning system detailed explorations of temperature data are inevitable. A close examination of the network of weather stations is the first step before further analysis. Iraq temperature data is gathered from Iraq network, which contains historical data of various weather variables for most states in the world. Iraq temperature data comes from a network of 29 meteorological stations as shown in the Figure3. Historical observations of minimum and maximum temperature variables (Tmin, Tmax) were collected for the period between 1 January 2011 and 31 march 2014.

Degree days can be estimated at observed locations (weather stations) while estimating degree days at other point locations requires some form of spatial interpolation techniques to interpolate temperature data and then estimating the degree days. The Spatial interpolation is more useful if a sufficient intensity of weather stations is available across the study area where the intensity of the network required depends upon the weather variable to be predicted [24]. Temperature variables, for example, are less variable over shorter distances.

Figure 3. The spatial distribution of the studied stations

IDW is widely preferred in climatic applications to perform interpolating surfaces. In [27], IDW has been used to estimate weather data (air temperature, relative humidity, and rainfall) for mesh grids with spatial resolution of (240*240 km) to view plant disease forecast image in Gyeonggi-do, Korea. In [6] IDW was used in estimating weather data to present GIS-based maps show the geographical distribution of crops growing degree-days (GDDs) within Iran. Also, the IDW is easy to implement, and captures local variations well. IDW is a deterministic technique considers the first law in geography "Everything is related to everything else, but near things are more related than distant things [26]. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Measured values that are nearest to the prediction location will have greater influence (weight) on the predicted value at that unknown point than those that are farther away as given in Equations (1) and (2). Based on the construction of the IDW formula, the choice of weighting function can change the resulted interpolation outcomes.

$$w(d_i) = d_i^k \qquad (1)$$

$$\hat{Z}(S_0) = \frac{\sum_{i=1}^{N} w(d_i) Z(s_i)}{\sum_{i=1}^{N} w(d_i)} \qquad (2)$$

Where:

d_i= the distance

$w(d)$ = The weighting function with power parameter k

$\hat{Z}(S_0)$ = The estimated value

$Z(S_i)$ = the observed value

S_0, S_i = Point locations

N= the number of calculated stations.

The Great Circle Distance formula [18] is used to calculate the geographic distances according to the Equation (3).

$$h = \cos^{-1}(\sin(lat_1) * \sin(lat_2) + \cos(lat_1) * \cos(lat_2) * \cos(lon_2 - lon_1)) * r \qquad (3)$$

Where:
lat_1, lat_2= latitudes of Points.
lon_1, lon_2= longitudes of Points.
r= Radius of the earth which is equal to 6378.1Kilometers.

Pest risk maps are powerful visual communication tools to describe where pest's growth spread. These maps inform strategic and tactical pest management decisions. Diverse methods are available to create pest growth maps and can potentially yield different depictions of risk for the same pests. In this research, we will deal with Google maps, which they are web based applications that provide detailed data and satellite views about geographical regions and sites around the world. Subgurim Google Maps API V4 with ASP.NET web application (C# programming language) to integrate Iraq data with this advanced software library to analyze and present the results on the map.

3. THE PROPOSED SYSTEM

The proposed system is used to generate simultaneous pest's growth heat maps depending on the temperature data stored in system database, pest's growth maps are the method of displaying the distribution of pests' growth stages in the field. The proposed pest risk mapping system executes many main steps; each step in this section will be described in details. The block diagram in Figure (4) illustrates the proposed system.

Step1: Identifying Pest and Date

This step requires selecting the pest to be monitored on a certain crop and identifying the date that on which a user want to show pest growth, the identified date must be large than the biofix date of the pest.

Step2: Data Set of the Specified Parameters

The proposed system includes a number of parameters that have great effect on the efficiency of the system in giving sufficient results; these parameters are local search radius, global search radius, minimum neighbors, and maximum neighbors. Local search radius and global search radius are two parameters help in estimating temperature data for unmeasured location, value of these parameters helps in searching which stations are near to the intended location and within its search radiuses. The local search radius value sets to 10km for data transforming from nearest station; hence, temperature data still constant around weather stations with area less than 50km. In this research, this value is decreased to get more accurate results as it is shown in the figure (5).

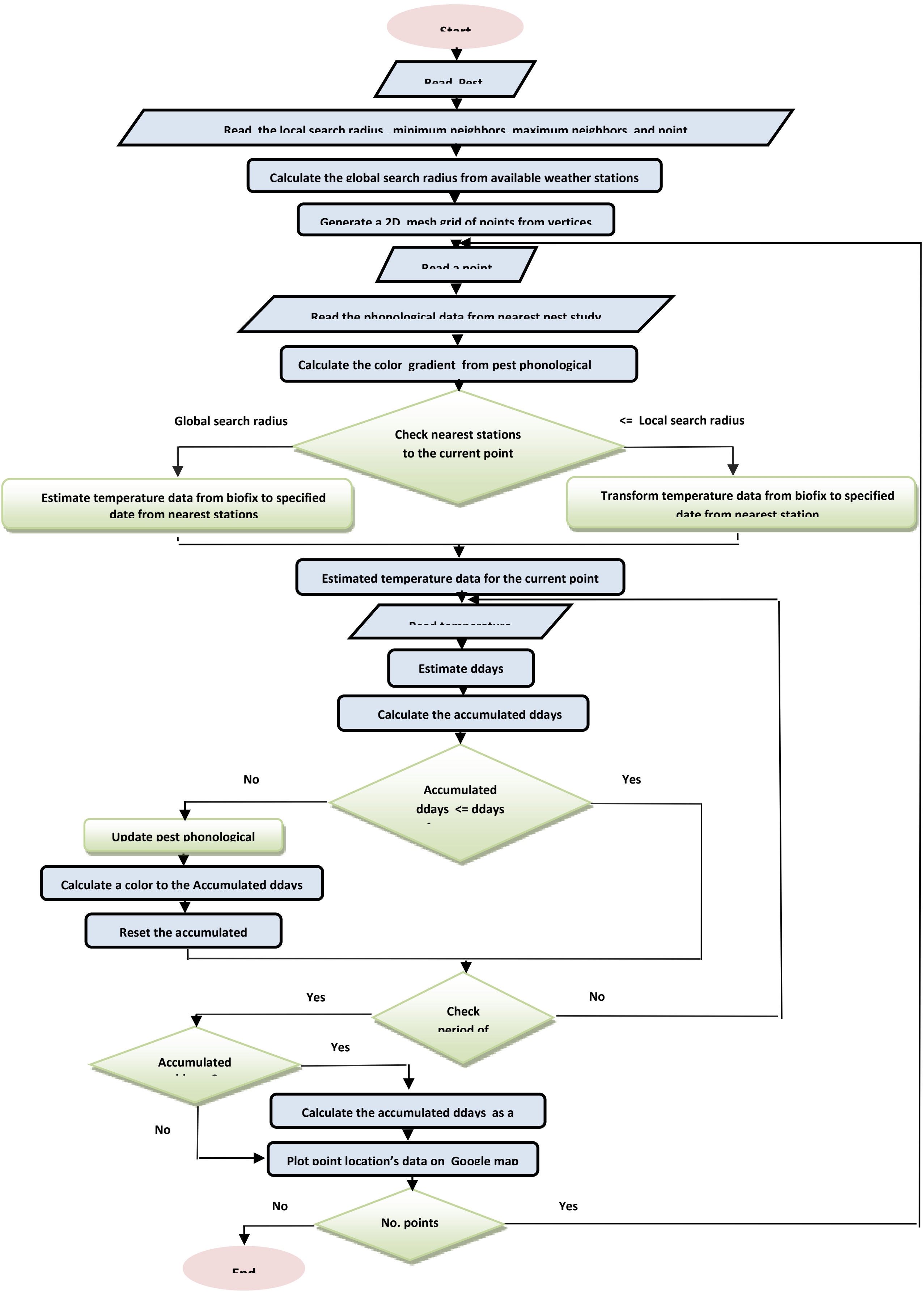
Start
Read Pest
Read the local search radius , minimum neighbors, maximum neighbors, and point
Calculate the global search radius from available weather stations
Generate a 2D mesh grid of points from vertices
Read a point
Read the phonological data from nearest pest study
Calculate the color gradient from pest phonological
Global search radius
Check nearest stations to the current point
<= Local search radius
Estimate temperature data from biofix to specified date from nearest stations
Transform temperature data from biofix to specified date from nearest station
Estimated temperature data for the current point
Read temperature
Estimate ddays
Calculate the accumulated ddays
No
Accumulated ddays <= ddays
Yes
Update pest phonological
Calculate a color to the Accumulated ddays
Reset the accumulated
Yes
Check period of
No
Accumulated
Yes
Calculate the accumulated ddays as a
No
Plot point location's data on Google map
No
No. points
Yes
End

Figure 4. The flow chart of pest risk mapping system.

The global search radius value is the maximum geographic distance between weather stations. For the global search radius, the number of nearest stations is considered in the calculations by using the minimum and maximum neighbors' parameters.

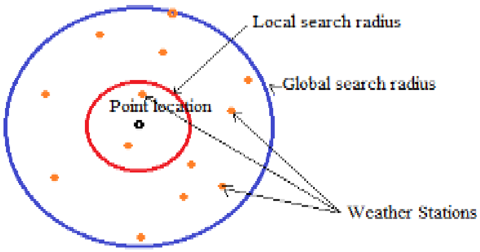

Figure 5. The global and local search radius of a point need to estimate its temperature data from weather stations.

Step3: Generating a Surface of Points

Most processes of surface generating are usually done using GIS software such as ArcGIS software. In ArcMap program, several steps are needed to be implemented on the world polygons layer using data management and analysis tools in order to create a surface of points that cover the studied polygon with identified resolution which specifies the number of points generated within the surface.

In this research, an algorithm is introduced which works to generate a 2D surface of points, this algorithm uses the coordinates of the study area boundaries to specify the starting points and breakpoints to generate the surface, and it is includes a decision parameter used to manage the resolution of the surface, where less value means generating a surface with high resolution by specifying the number of points in both latitude and longitude coordinates of the generated points. This algorithm includes the pseudo code of the Ray-crossing algorithm [12] to achieve our objective in generating a surface of points confined in the studied area (e.g. Iraq).

Step4: Colors Gradient

Plotting the resulted degree days on Google map require defining a gradient of colors which represents pests phonological events (e.g. Eggs, Larvae). In this proposed system, a band of 26 colors is defined to be utilized on the map; this band will be distributed to sub-bands according to pest growth stages. Each color in the sub-band will have a degree days range calculated from the average degree days of the pest growth stage that belong to it.

Step5: Estimating Temperature Data

For each unmeasured location, temperature data for the period between the biofix date and the specified date is either directly observed or interpolated from a set of neighboring stations according to the local and global search radiuses, if there are a number of weather stations located at the local search radius, temperature data will be transformed directly from the nearest station. The interpolation process is implemented if there is no weather station located in the local search radius.

Step6: Estimating Degree Days from Temperature Data

This step works on calculating the accumulated degree days of each point location from the estimated degree days of the point's temperature data. Estimating the degree days from temperature data is done according to the specified degree-day model and then summiting the accumulated degree days. After the accumulated degree days were calculated, they will be represented as colors to represent the different reached growth stage.

Step7: Representing the Resulted Data on Google Map

Google maps API has several layers with several resolutions, results are plotted on the vector layer of Google maps with resolution (200*200) km, where each point in the surface is plotted with radius(3.3) meter and all plotted colors have the same significance on all maps.

4. RESULTS

The IDW is found to be easy to implement and it less the cost of time when it uses to estimate an amount of temperature data to a surface of points in a web application. Therefore, interpolating temperature data for each point location in the surface make the system has a general structure to estimate pests degree day's according to the all available pests study locations, considering that most researches on pests are done in locations farther away from weather stations. Single sine model is practical tool to analyze organisms with assuming a linear functional response to temperature data and depending on a few numbers of parameters that can calculate from simple experiments of growth. However, it's necessary to consider that the shape of temperature curve changes with latitude and elevation and can affect the accuracy of models since there is need to provide the models with accurate temperature data for each location. The IDW interpolation technique, single sine model, and Google maps API are implemented within the proposed system environment. The proposed system includes a number of web interfaces to implement its 'objectives. The system is executed on the local host of the computer. In this test, the center of Google maps was set to Baghdad city coordinates to let us navigate our desired location where we want to show a pest growth in it as it is shown in Figure 6.Two pests are selected in this test: Date mite and Date bug as it is shown in Figures (7,8). Pest risk map was generated with spatial resolution 200km*200km.

5. Conclusions

In this research, the outcome results can be summarized as follows:

A. The results show that the IDW interpolation technique represents the best choice to estimate temperature data which is simple to implement and it is important to consider the size of task where there is need to estimate temperature data for a surface of point locations and should end in good results.

B. Slippy maps technique has several features and can be applied in other systems (e.g. tourist information system using the georeferencing and routing service), the professional use and programming with Google Maps API eliminates the need to use some Mapping softwares. In our system a new implementation of pests risk mapping using Google maps APIs was introduced.

C. Proposing such system with the implemented techniques and tools to track pest’s growth and predict the emergence of them in different regions at the same time is fundamental to get an integrated pest management program in Iraq by using the forecasted information to determine the time of pesticides spray in order to control pests and decrease the effects of attacks.

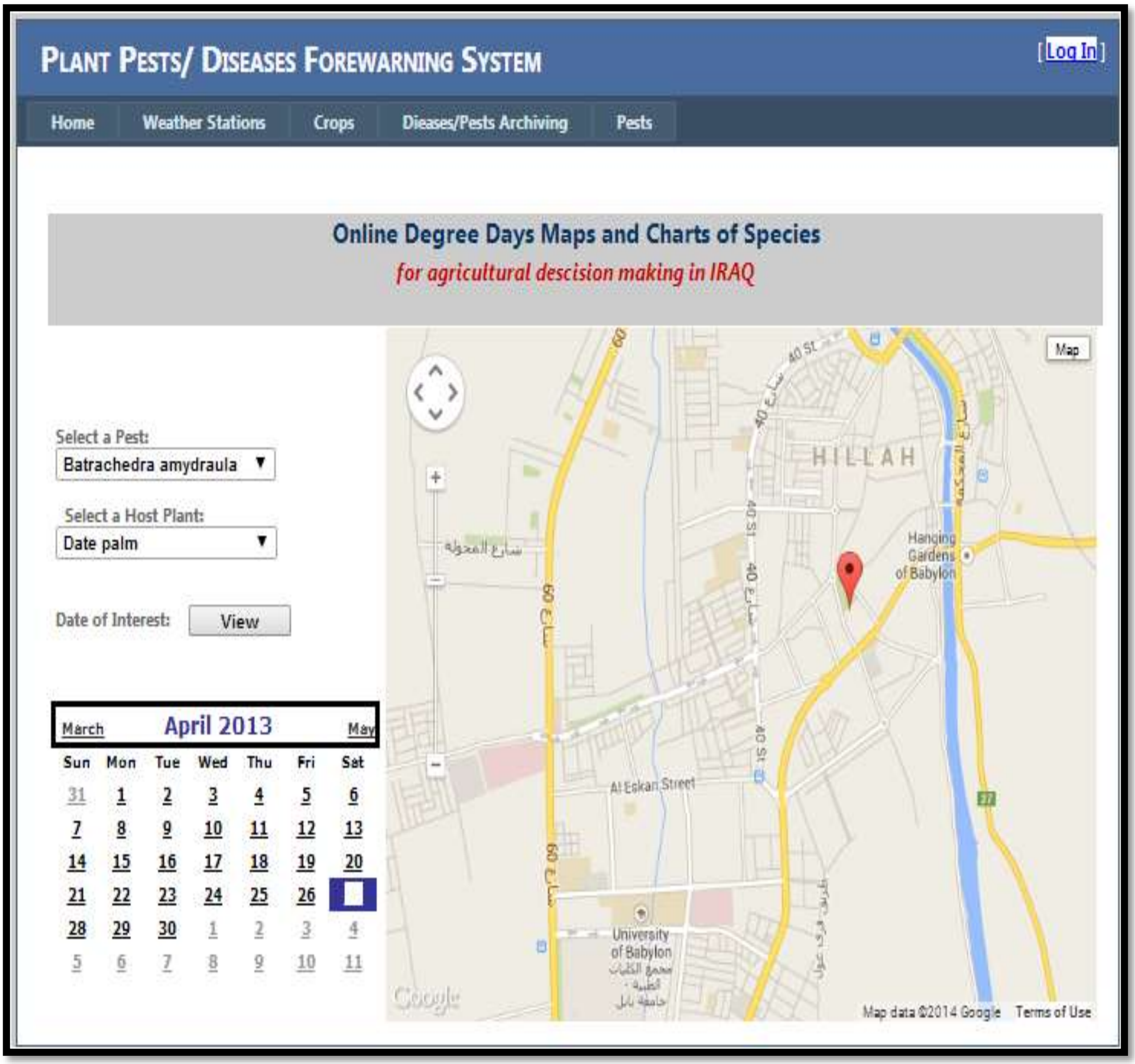

Figure 6. Home webpage show user specified location and other specified information that he/she want to view pest activity.

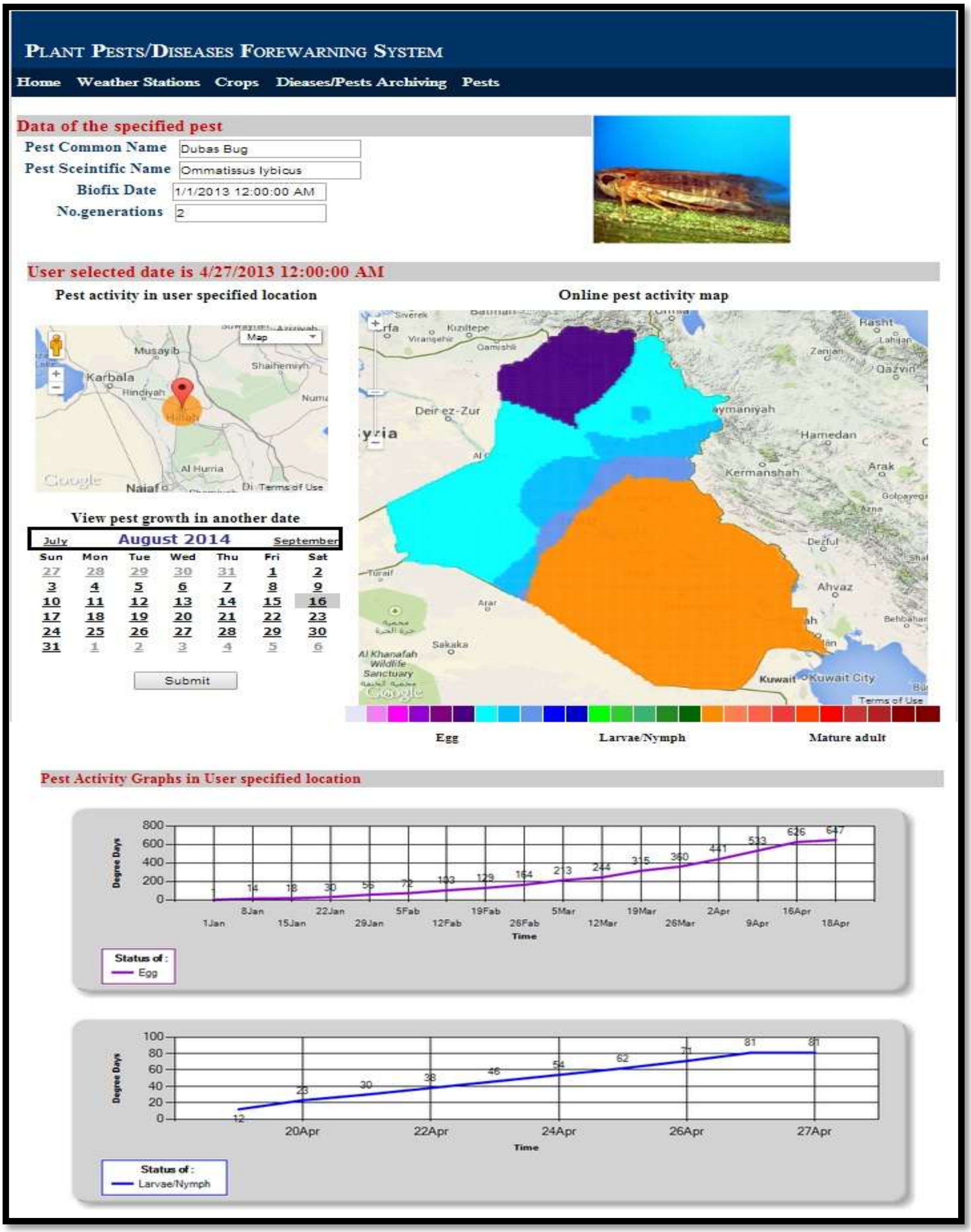

Figure7. Pest activity webpage of the selected Date moth pest in Iraq.

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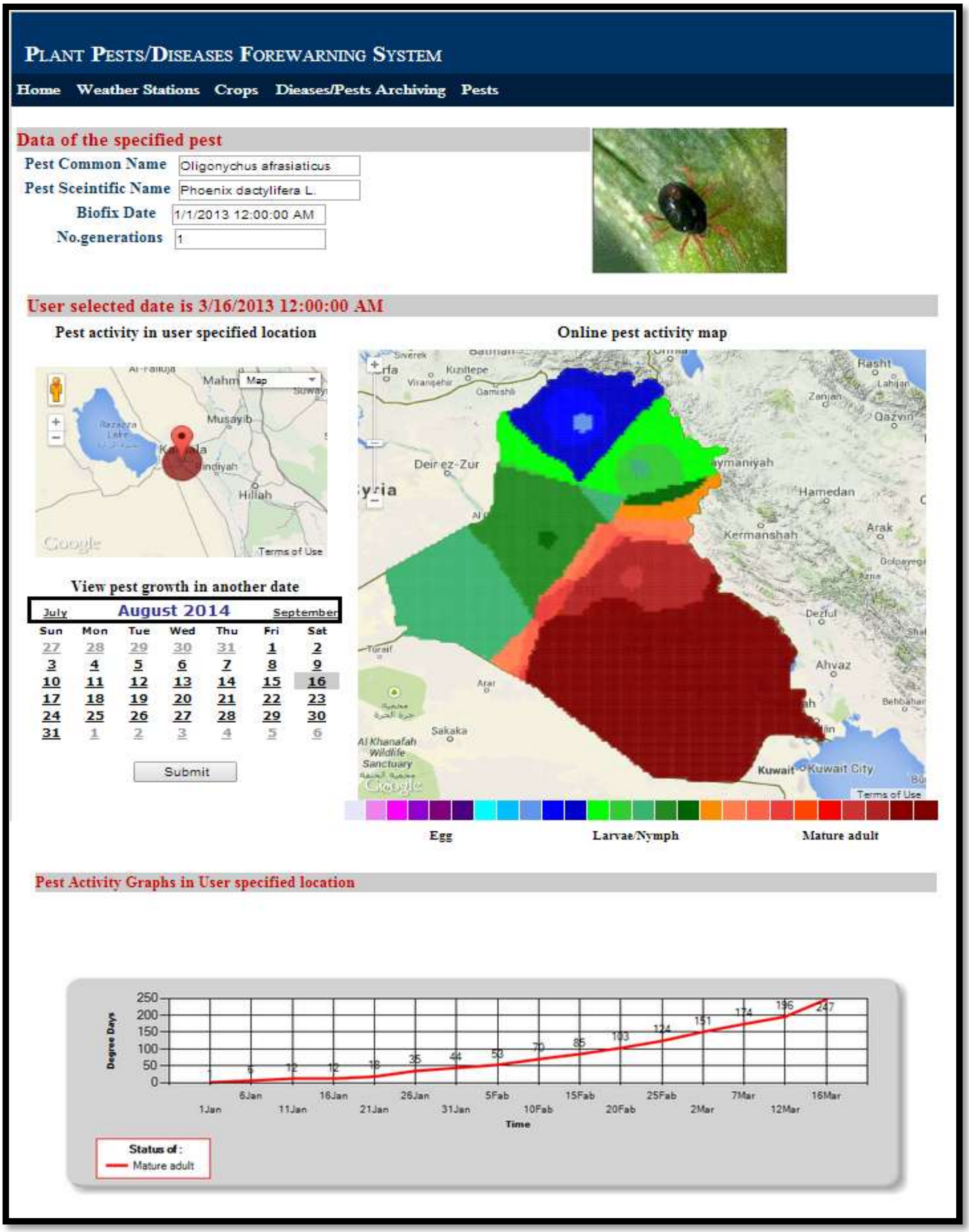

Figure 8. Pest activity webpage of the selected Date mite pest in Iraq.

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