Al-Kindi, K., Kwan, P., Andrew, N., & Welch, M. (2017). Modelling spatiotemporal patterns of dubas bug infestations on date palms in northern Oman: A geographical information system case study. Crop Protection, 93, 113-121.
http://dx.doi.org/10.1016/j.cropro.2016.11.033

Modelling spatiotemporal patterns of Dubas bug infestations on Date palms in northern Oman: A Geographical Information System case study

Khalifa M. Al-Kindi[1,*], Paul Kwan[1], Nigel R. Andrew[2] & Mitchell Welch[1]

[1]*School of Science and Technology, University of New England, Armidale NSW 2350, Australia*

[2]*Centre for Behavioural and Physiological Ecology, Zoology, University of New England, Armidale NSW 2350, Australia*

Corresponding author: kalkindi@myune.edu.au

Abstract

The aim of this paper is to demonstrate how Geographical Information System (GIS) can be used effectively to study Dubas bug (DB), *Ommatissus lybicus* Bergevin, infestations in date palm (*Phoenix dactylifera*), tree of palm family (Arecacae or Palmae) that occurred in northern Oman during 2006-2015. The ability to produce geographical and spatiotemporal layers using GIS is expected to serve an important role in both monitoring and surveillance of DB infestation and its impact in the study area. By using of spatial analytic and geostatistical functions in ArcGIS 10.3[TM,1], data that quantified the infestation levels of DB over a 10-year period from 2006 to 2015 were used to map and model the risk of infestation spatiotemporally. We modelled the spatiotemporal risk of DB infestation by performing hotspot analysis using the Getis-Ord statistic, Gi*. Our results show that annual hotspots over the study period were mainly concentrated in the mountain plains, particularly where farms are located between gradient elevations. Furthermore, the distribution pattern varied considerably with time and space. These results demonstrated the usefulness in following annual DB infestation patterns by studying the average seasonal infestation levels and distribution of hotspots as they can

[1] http://www.esri.com/software/arcgis

facilitate the allocation of resources for the treatment of infestations and allow for more effective monitoring of its influence on date palm trees.

Keywords: *dates, Dubas bug, geographical information system, spatiotemporal, Oman,* temporal hotspot, Phoenix dactylifera

1. Introduction

Date palm (*Phoenix dactylifera*), a palm tree belonging to Arecacae family, cultivation is economically important in the Sultanate of Oman, with significant financial investments coming from both the government and private sectors. However, a global Dubas bug (*Ommatissus lybicus* Bergevin; referred to as DB) infestation has impacted regions including the Middle East, North Africa, Southeast Russia, and Spain, resulting in widespread damages to date palms (Abdullah, Lorca, & Jansson, 2010; Blumberg, 2008; Howard, 2001; Khalaf & Khudhair, 2015). Dubas bug impacts are severe in Oman, Southern Iraq, and Southern Iran while not as severe in other countries such as the United Arab Emirates, Saudi Arabia, Egypt, Tunisia, Libya, Algeria, and Morocco. Hussain (1963) reported that heavy infestations occurred mostly along rivers, with both male and female date palms damaged equally.

The DB is a sap-feeding insect. Both adults and nymphs suck sap from date palms, causing chlorosis. The honeydew of DB leads to accumulation of black sooty mould on foliage that disrupts photosynthesis. Heavy infestations weaken plants and can even result in plant death (Al-Khatri, 2004; Howard, 2001; Hussain, 1963; Kinawy & Al Siyabi, 2012; Mahmoudi, Sahragard, Pezhman, & Ghadamyari, 2015; Mokhtar & Al Nabhani, 2010). Gassouma (2004) reported that DB could reduce the crop yield by more than 50% during heavy infestations.

Two generations of DB occur annually. In the spring generation, eggs start hatching from February to April where nymphs pass through 5 instars to become adults in approximately 6-7 weeks. The eggs aestivate or hibernate during hot season (i.e., summer) until the autumn generation where they start hatching from late August to the last week of October. A nymph takes about 6 weeks to develop into an adult, which lives for about 12 weeks. Each female can produce more than 120 eggs, which are laid by insertion into holes in the tissue of date palm fronds at the end of each season (Elwan & Al-Tamimi, 1999).

The DB has been recorded in Oman as early as 1962. The Ministry of Agriculture and Fisheries (MAF) has made huge efforts to control its infestation. Insecticides were evaluated for DB management by air and ground spraying in spring 1980. However, the most appropriate pesticides are restricted because of their side effects (e.g., irritation) (Al-Yahyai & Khan, 2015). In addition, these methods are expensive and can have negative environmental impacts on non-target species (Al-Azawi, 1986; Hussain, 1963), in particular on natural enemies (H. El-Shafie, 2012; Shah, Naeem, Nasir, Irfan-ul-Haq, & Hafeez, 2012) of the DB as well as on human health . Furthermore, chemical control measures have had limited successes in Oman, where DB continues to pose a major challenge for the agricultural industry (H. A. El-Shafie, Peña, & Khalaf, 2015).

Although there are a number of studies on the biology and ecology of DB (Al-Deeb, 2012; Jasim & Al-Zubaidy, 2010; Thacker, Al-Mahmooli, & Deadman, 2003), the use of geographic information systems (GIS), remote sensing (RS) and spatial analysis of DB infestations in the sultanate of Oman has been limited. Spatial analysis can be used to estimate the risk of diseases and insect infestations across affected areas and offer insights into the nature of their spread and clustering (Ai-Leen & Song, 2000).

In our study, spatial clustering methods are of significant value in the identification of hotspots of affected area. Until now, temporal aspects of DB infestation have largely been ignored, leading to difficulties in assessing the infestation levels of DB outbreaks and decision making.

Understanding the historical and spatiotemporal patterns of occurrences of the DB infestation at the landscape level is expected to provide invaluable insights into how outbreaks develop, persist and subside. The main objectives of this paper are to (a) illustrate the spatiotemporal changes of DB infestation risks based on annual data from 2006 to 2015, and (b) specify the degree of change of their infestation levels. The findings are important for providing spatiotemporal traces that could improve and develop management as well as surveillance systems for DB infestations.

2. Materials and Methods

2.1 Study area

Oman has diverse topographical and climate eco-regions that allow for cultivation of several types of date plants, particularly in the northern coastal and the interior governorates (Al-Busaidi & Jukes, 2015). In this study, we focused on northern Oman (26°50N to 22°26N, and 55°50E to 59°50E) (Fig. 1). According to the Ministry of Agriculture (MAF) (Annual Report,1990), this area contains the highest level of DB infestation and has resulted in many direct and indirect damages to the infested date palms and nearby trees, causing up to 50% crop loss during a heavy infestation (Al-Khatri, 2004; Al-Yahyai & Al-Khanjari, 2008b; Ali, 2010; Mani et al. 2005). The study area covers a size of ~ 114,336 km^2 and includes nine governorates. The plantation of date palms on the coastline plain approximates 49% of the total distribution (Musandam 3%, Muscat 4%, Al-Batinah North and Al-Batinah South 41.87%) while another 50% are distributed in the interior plain (Al-Dakhliah 14%, Al-Dhahirah and Al-Buraymi 17%, Ash-Sharqiyah North, and Ash-Sharqiyah South 19%) (Al-Yahyai & Al-Khanjari, 2008a).

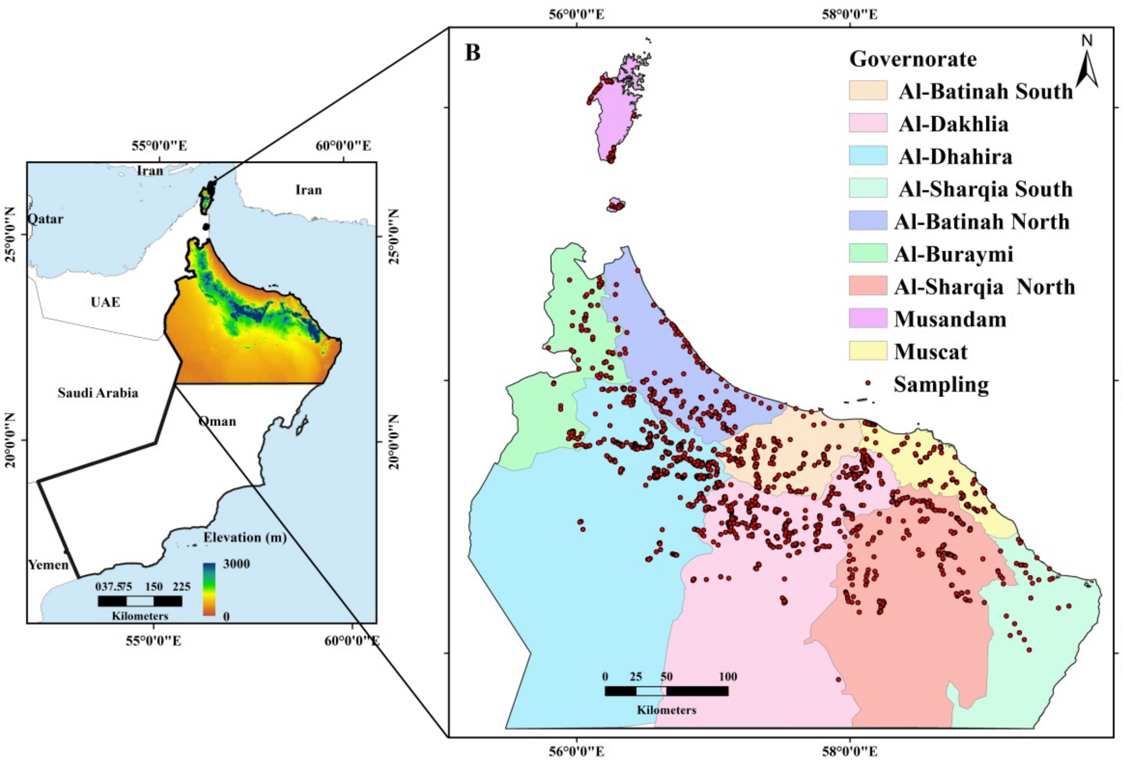


Fig 1. (a) Location of the study area with positions of samplings points (sites), and (b) governorates in northern Oman.

2.2 Data

Data on DB infestations and their impact determined by observations of palm trees from 2006 to 2015 were obtained from the MAF. These data comprise spatial coordinates (longitude & latitude of sites), governorate, infestation level and the method of data collection for DB infestation. In Oman, two methods have been used to identify the economic threshold of DB infestation during autumn and spring generations. The first method involves counting the number of nymphs on each leaflet. The MAF considered a slight infestation with five nymphs (instars) on the leaflet, a moderate infestation with 5 to 10 nymphs per leaflet, and a heavy infestation with 10 or more nymphs per leaflet (Al-Khatri, 2004). The second method involves determining the infestation level is estimating the number of insects by counting the number of honeydew droplets from palm trees (Mokhtar & Al Nabhani, 2010).

In this study, we selected the counting of nymphs method to create a geodatabase. The actual observations included presence data. We classified the DB infestation levels into 4 groups (very low, low, moderate and high) in ArcGIS 10.3 as follows: very low infestation (less than 5 nymphs per leaflet; low (5 to 7 nymphs per leaflet); moderate (8 to 9 nymphs per leaflet); and high infestation (10 or more nymphs per leaflet. The samples were collected in both seasons (spring and autumn generations) from 2006 to 2015 pried. However, we calculated the average over the two seasons for analysis. All datasets and GIS layers that were collected from the Sultanate of Omani Ministries and Departments were projected onto the WGS 1984 UTM zone 40.

2.3 Spatial Analytic Methods

2.3.1 Measuring geographical distribution

Measuring geographical distribution (MGD) toolset in ArcGIS was used to calculate the characteristics of DB infestations (centre, compactness, track change), and to compare DB infestation distributions among years. The mean centre of infestations in the landscape over the period of 10 years was computed and mapped to show DB congregations annually. MGD can also be used to determine or predict where DB infestation is spreading and to map centres of infestation levels monthly.

MGD can help to generate plans, approaches and instruments to monitor the development, absence, presence, and density of a set of features (Wong & Lee, 2005). The mean centre geographical analysis method was used to decide whether or not DB distribution shifted annually based on two generations per year. Data obtained from the MAF, such as DB infestation levels, were used to calculate a mean centre and to investigate and calculate the change in potential DB infestation areas. The mean centre can be computed in two dimensions by:

$$\bar{X}_w = \frac{\sum_i (w_i X_i)}{\sum_i w_i} , \quad \bar{Y}_w = \frac{\sum_i (w_i Y_i)}{\sum_i w_i} \qquad (2)$$

where $\bar{X}_w$ is the weighted mean X-coordinate, w_i is weight, $\bar{Y}_w$ is the weighted mean Y- coordinate. We used the standard distance tool to calculate both the weighted difference in distance between the points and the mean centre of DB infestations (hotspot) in order to obtain the average deviation from the mean. Additionally, the calculated weighted mean centre is useful when analysing the distribution of values in the area. This method provides a better measure of DB infestations around the mean, instead of being clustered at opposite sides of the study area.

The standard deviational ellipse (SDE) tool was used to measure the orientation, direction and spatial tendency of the distribution of DB infestations. We calculated the orientation of the areas that have been infested to investigate if their orientation is associated with factors such as mountains, valleys, and date palm densities. The SDE can also be used to compare infestation levels between different seasons or years of DB generations (e.g. spring and autumn).

We used SDE to calculate and draw an ellipse up to one standard deviation for known observations in order to observe the occurrences of DB infestation within the study area over the 10-year period. SDE is termed a standard deviational ellipse because of the standard deviation of the x- and y-coordinates from their average values, called the mean centre (Wong, 1999). The Euclidean approach was used to calculate the orientation of DB infestation distribution because it computes the shortest distance between values. The SDE is defined as:

$$SD_x = \sqrt{\frac{\sum_i (X_i - \bar{X})^2}{n}} , \quad SD_y = \sqrt{\frac{\sum_i (Y_i - \bar{Y})^2}{n}} \qquad (3)$$

where SD_x is the standard distance for the x-axis, and SD_y is the standard distance for the y-axis, n is the number of features, X and Y are the coordinates, $\bar{X}$ and $\bar{Y}$ are the mean X and Y-coordinates.

2.3.2 Mapping hotspots

Many spatial statistics can be used to investigate the distribution of insect infestations. For example, one can conduct spatial autocorrelation analysis using Moran's I to determine the spatial distribution or dispersal pattern (i.e. random, clusters and clumped) of the subject (DB in our study) by measuring the relationship between the population density (i.e. infestations sites) and spatial factors such as distance between populations (Al-Kindi, Kwan, Andrew, & Welch, 2016; Griffith, 1987). It can be used to measure the spatial autocorrelation of insect infestations based on the infestation locations and magnitudes simultaneously. However, Moran's I, either general or local, can only detect the presence of a cluster of similar values. It cannot tell whether the cluster is made of high or low values.

Geary's index can be used to measure the similarity of nearby features or similar values occurring together. However, like Moran's I, it cannot determine whether clusters are composed of high or low values. The G-statistic can be used to separate clusters of high from clusters of low values (Getis & Ord, 1992). The global G-statistic is based on a stated distance d. The weight can be based on some $G(d)$ in order to evaluate its statistical significance. In addition to the global G-statistic, which is similar to Moran's I, a local version of the G-statistic (Anselin & Getis, 2010; Ord & Getis, 1995), denoted by $G_i(d)$, is often described as a tool for *hot spot* analysis. A cluster of high positive Z scores suggests the presence of a cluster of *hot spot* values. On the other hand, a cluster of low positive Z scores suggests the presence of a cluster of *cold spot* values. The G_i^* of a hotspot can be computed by:

$$G_i^* = \frac{\sum_{j=i}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{s \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}} \quad (1)$$

Where G_i* represents the value of G* for feature *i* at a distance *d*. The value of each neighbour x_i is multiplied by the weighted target-neighbour pair w_{ij}. A G_i* value close to 0 indicates that there is neither low nor high concentration of values nearby the target feature. This happens when the surrounding values are close to the mean, or when the target feature is bound by a mixture of low and high values. The use of Gi* adds statistical significance to hotspot analysis by considering all values within distance d. Moreover, it is better at predicting spatial clustering patterns such as hot/cold spots over an entire study area based on the statistical significance of the risk factors (Kulldorff, Athas, Feurer, Miller, & Key, 1998; Neill, Moore, Pereira, & Mitchell, 2004). Statistical analysis using G_i* is also particularly helpful for resource allocation and decision making, and can be combined with infestation level indices to produce a useful measure. This measure implies the risk of DB infestations.

For our analysis, a set of 616 sites that were randomly sampled across the study area, once for each of the two seasons, was used over the period 2006-2015. The Gi* statistics was applied to examine the local level of yearly (two seasons per year) temporal risk in order to model both hot spot and cold spot sites, according to the values of DB frequency index, the infestation levels and degree of geographically homogeneity. The Euclidean distance was used to computer a z-score and a p-value for each site of the study. The GIS function calculates a z-score for each feature at the specified distance. We conceptualised the spatial relationships between locations of DB infestation in the nine governorates that are studied by utilizing fixed-distance bands. This allows for the accounting of DB infestation levels within the boundaries of the study area, while excluding irrelevant data from outside the boundaries. The proposed method has been shown to be generally more appropriate than the inverse distance method provided by spatial statistical tools for performing geographical cluster pattern analysis (Mitchell, 2005, pp. 172-180).

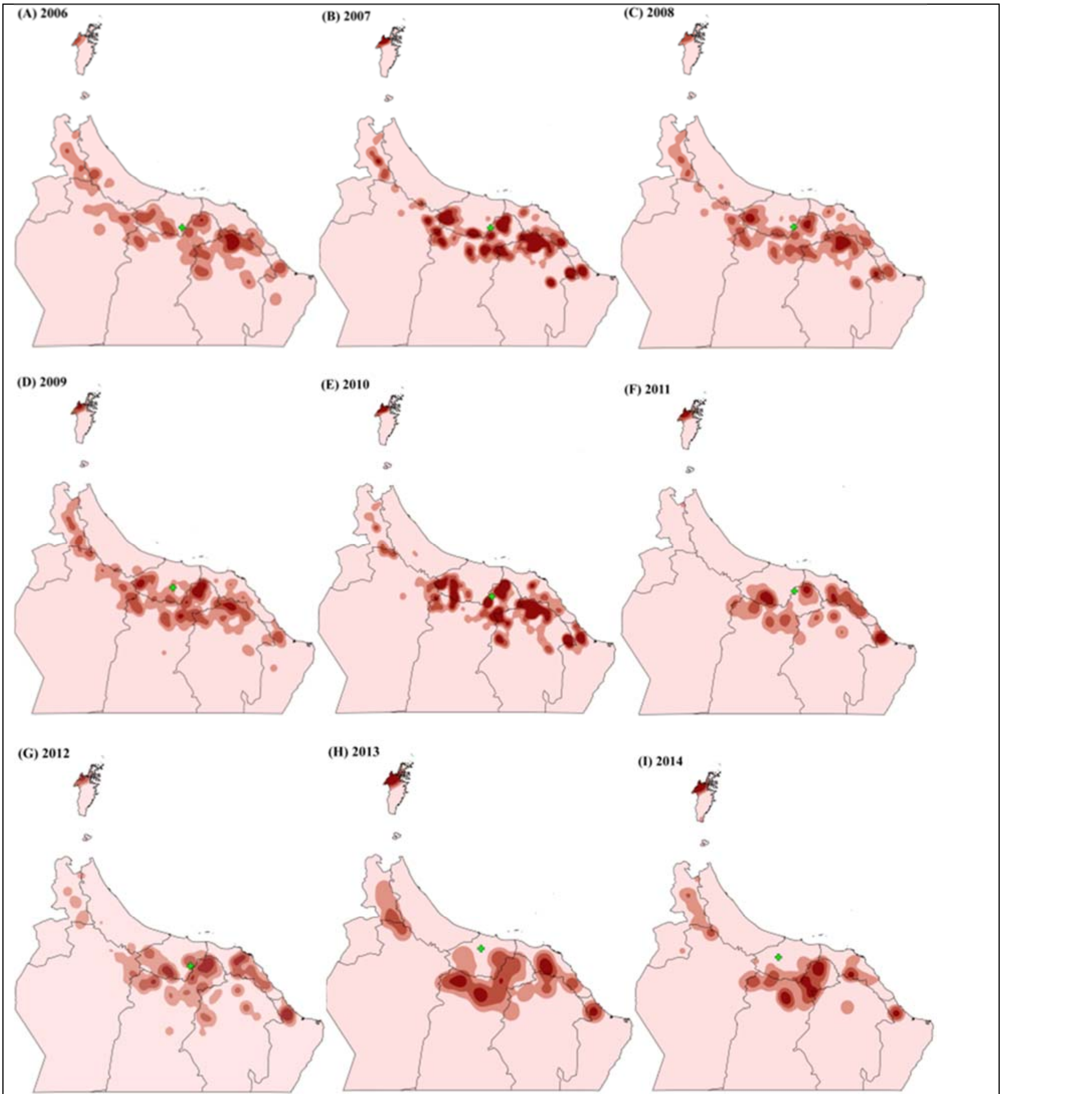
Kernel density estimation method was used to calculate the total area at a high risk. It was applied as the vectorization function (convert raster to vector) to get a polygon shapefile. This approach can be used to calculate the size (area) per hectares of infestation levels of DB for each year from 2006-2015.

3. Results

The results are presented on an annual basis from 2006 to 2015 in Figure 3. Locations of hotspot with significant infestation levels are indicated. Spatiotemporally, the yearly hotspots are distributed in most of the nine governorates in the northern part of Oman. However, some of the regions that were identified as a high-risk area exhibited infestation level changes from low to high over some of the 10-year period. For example, the northern parts of Al-Sharqia North governorate in particular, was identified as a high-risk area with (Z-Score $\geq$ 4.80; $p = 0.01$) in both 2006 and 2015, but was a medium-risk area in 2011-2013, and a low and very low-risk area in 2014 (see Figure 3).

Similarly, the north-eastern part of the Al-Dhahirah governorate was a high-risk area in 2007, a medium-risk area in 2009, 2010 (NE), and 2013 (NW), but a low-risk area in 2006 (N and NE), 2012 (NW), and a very low-risk area in 2011 and 2014 (refer to Figure 3). Figure 4 shows the number of locations (or sites) of high DB infestation from 2006-2015 based on the condition, 2.50 $\leq$ Z-score. For example, in 2006, 92 locations were identified as area of high risk, while the number of sites at high risk decreased in 2007, 2008 and 2009 respectively. In essence, the patterns of hotspots and high-risk areas were shifting and the DB infestation risks increased as well as decreased over the 10-year period.

The average annual risk map for the 10-year period shows that most of the DB hotspots occurred in the nine central governorates of northern Oman (see Figure 3). Based on the average DB infestation level for the 10-year period, we identified northwest Musandam, northern Ash-Sharqiyah, northern Al-Dakhliah, and Southern Al-Batinah as high-risk areas for most of the years, while the northern Al-Batinah governorate was identified as a very low-risk area. The infestation levels also changed from one year to the next (refer to Figure 3). Our data and analyses provided very useful insights into the understanding of spatiotemporal risk variations during the last 10 years.



(A) 2006
(B) 2007
(C) 2008
(D) 2009
(E) 2010
(F) 2011
(G) 2012
(H) 2013
(I) 2014

(J) 2015

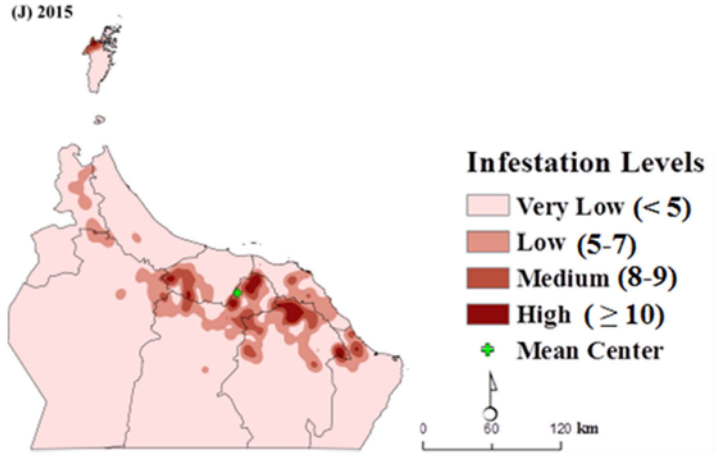

Infestation Levels
Very Low (< 5)
Low (5-7)
Medium (8-9)
High (≥ 10)
Mean Center
0 60 120 km

Fig3. Density and distribution of hot- and cold spots of DB infestation levels observed in date palms from 2006 to 2015. The scale in all maps is the same.

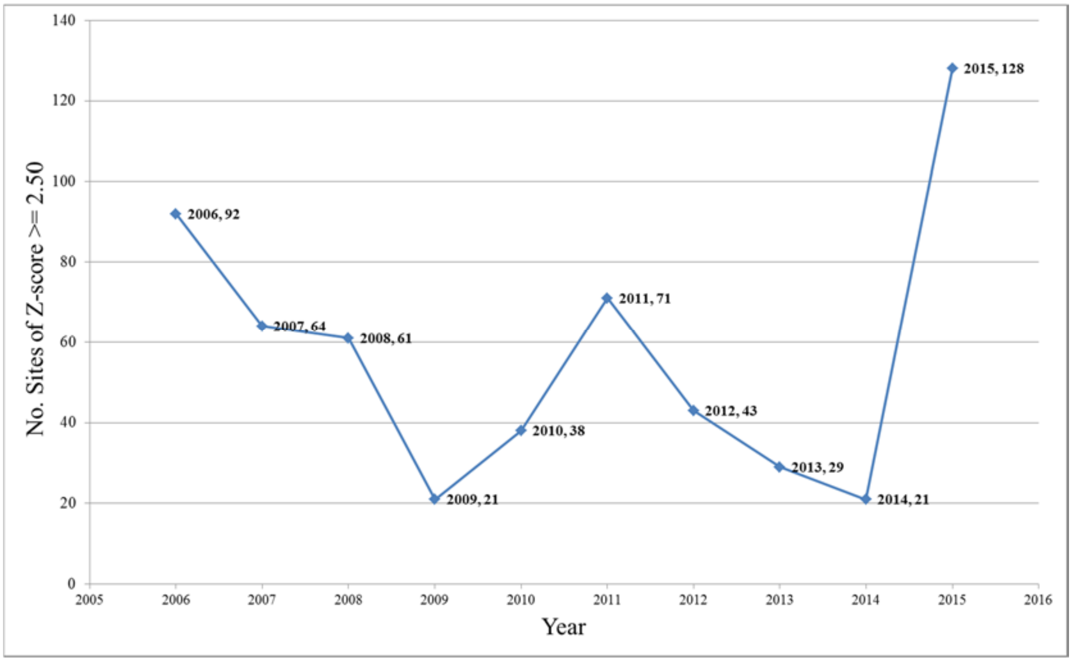


Figure 4. Changes in number of DB hotspots, satisfying $2.50 \leq$ Z-score, for the study area from 2006-2015. Detailed Z-scores and p-values for each hotspot can be found in the supplementary material.

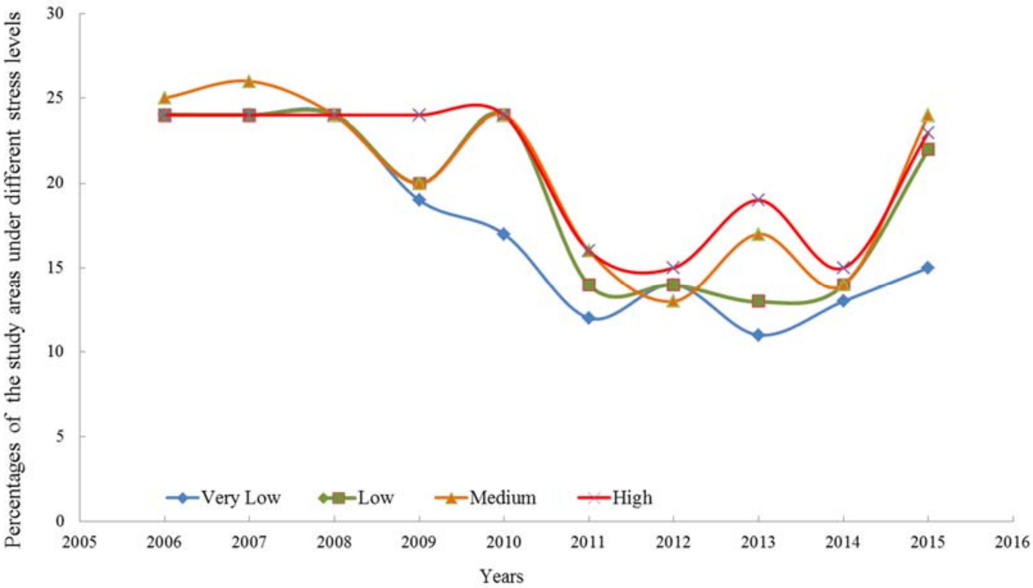


Figure 5: Percentages of infested areas under different infestation levels from 2006-2015.

Our analysis revealed that the percentages of infested areas with high-risk ranged from 15% to 24%, medium-risk areas ranged from 13% to 26%, and low-risk areas ranged from 11% to 24% in most years (see Figure 5). The percentage of high-risk areas increased from 2006 to 2010 and then decreased from 2012 to 2013. However, it increased again in 2013 and decreased in 2014, then appeared to increase again in 2015. The percentage of medium-risk areas also showed fluctuations: an increase in 2006 and 2007, a decrease in 2008 and 2009, an increase in 2010, a sharp decrease in 2011 and 2012, an increase again in 2013, a decrease in 2014, and lastly an increase in 2015 (refer to Figure 5). The raster map was used to calculate the infestation density and to obtain areas with hectares-sized infestations in the 10-year period (see Figure 6).

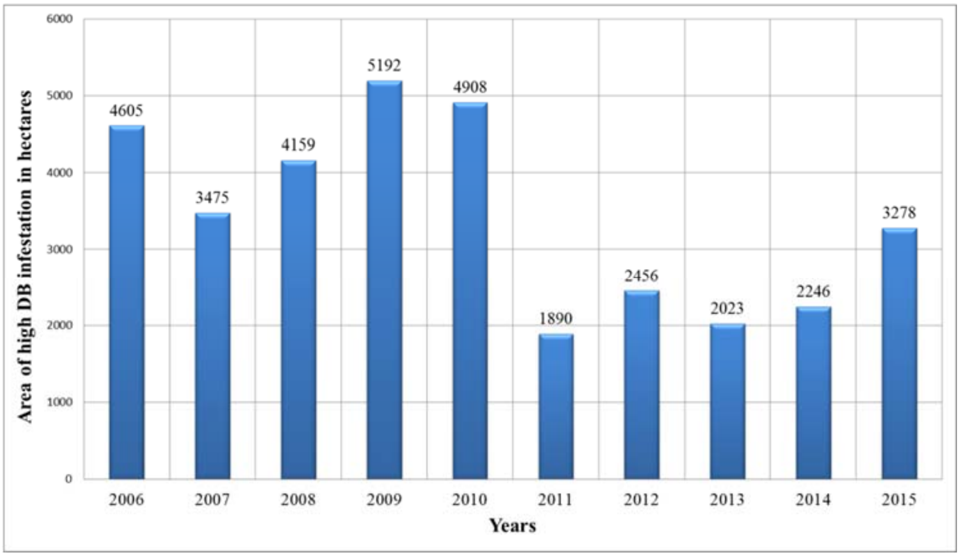


Fig.6 Area of high DB infestation in hectares from 2006-215.

Table 1: Change in mean centre locations in the 10-year period (highlighted in green colour in Figure 3).

From Year	Mean Centre-N	Mean Centre-E	To Year	Distance (km)	Mean Centre-N	Mean Centre-E	Degree/ Angle
2006	23.261680	57.775538	2007	9.04	23.277916	57.862190	10.61
2007	23.277916	57.86219	2008	2.25	23.285921	57.841882	158.49
2008	23.285921	57.841882	2009	21.63	23.378982	57.655222	153.50
2009	23.378982	57.655222	2010	30.22	23.250602	57.914436	-26.35
2010	23.250602	57.914436	2011	13.99	23.376899	57.926360	84.61
2011	23.376899	57.92636	2012	9.37	23.348342	57.838539	-161.99
2012	23.348342	57.838539	2013	38.55	23.583068	57.559798	139.90
2013	23.583068	57.559798	2014	12.44	23.510745	57.432013	-150.49
2014	23.510745	23.510745	2015	50.52	57.899768	57.899768	152.90

Table 1 shows the changes in the weighted mean centre (highlighted in green colour in Figure 3) of DB infestations for the nine central governorates of northern Oman from 2006 to 2015. The population centre was initially located in the Al-Batinah South Governorate. However, animation of the changes revealed an unsteady movement of the weighted mean centre for each year. For example, in 2006 the weighted mean centre was located at (23.261° N, 57.775° E) but shifted to (23.277° N, 57.862° E), which was 10.61° to the east and within 9.04 km. Another example was a weighted mean centre shift of 30.22 km within -26° from 2009 to 2010 (see Table 1).

An ellipse displayed in our results showed the DB infestation orientation (see Figure 7). We observed that the distribution of DB infestations shifted between preferred habitat locations in our study area while the orientation coincided with natural features, such as streams (i.e. dry river) or valleys with surrounding mountains. Additionally, SDE showed that the DB infestations have orientations and directions, which revealed a spatial trend in the 10-year period. The magnitude of standard deviation differed from year to year (refer to Figure 7). For example, the weighted size of the ellipse was 125.14 km (minor axis) and the length of the ellipse was 320.84 km (major axis) in 2008, while the weighted size of the ellipse was 130 km (minor axis) and the length of the ellipse was 322 km (major axis) in 2009 (see Figure 7).

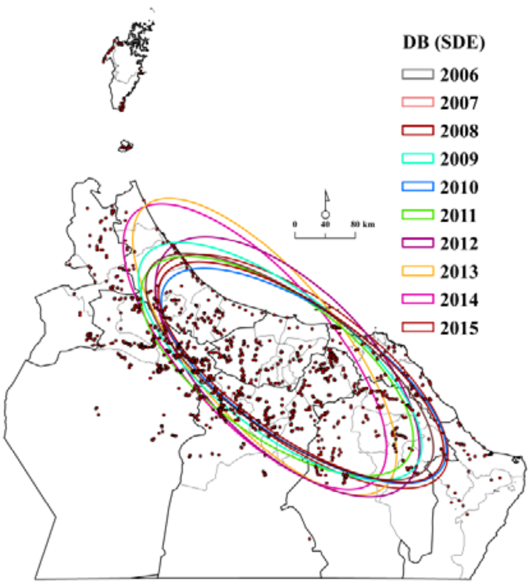


Figure 7: Standard deviation ellipses (SDE) revealing DB infestation sightings.

4. Discussions

To understand the distribution and prevalence of DB infestations, highly detailed and sophisticated information are needed to clarify complex gene-environmental interactions. Spatial information technologies, such as GIS and remote sensing, are important tools for visualising and analysing invasive insect infestations (in this study, DB) and associated entomological and agricultural data, which together describe factors that can facilitate the management and control of infestations.

Extraction of spatial patterns was the first step in understanding the phenomenon of DB infestations. Our results shown in Figure 3, based on the 10-year period of 2006-2015, show varying infestations (i.e., some regions/conditions led to more absence/presence of hot-or cold spots than others). The results were able to reveal very active areas of infestations. In addition, by applying procedures such as hotspot detection and kernel density estimation, we were able to identify spatial regions showing infestation events with a higher likelihood. The hotspots indicated potential outbreaks as well as revealing the underlying cause of infestation.

The weighted mean centres (marked with green colour) shifted during the 10-year period (see Figure 3 and Figure 4). The ability to determine a weighted DB infestation centre is useful for tracking changes in the distribution because it works well especially when analysing the distribution of values associated with an area.

One reason for the continued occurrences of DB infestation, shifts, and changes between governorates reported in this study is probably the failure of current control approaches that have been used since the 1980's to limit the spread of DB infestation in spite of achieving some successes in reducing their transmission. Another possible reason could be that DB breeding sites may have been overlooked or may not have been identified as risk areas. In addition, the annual data may not be sufficient enough to determine the real reasons behind the heavy presence of DB.

Our results showed that annual hotspots over the study period were mainly concentrated in the mountain plains, particularly where farms are located between gradient elevations and that their distribution patterns varied considerably with time and space. However, we believe that climatological and environmental conditions, together with other factors, are very important in determining the distribution and survival of any species, both plants and animal (Shah, Mohsin, Hafeez, Naeem, & Haq, 2013). The same applies to the DB. For example, links between DB hotspots, cold spots, density, presence or absence results can be useful in our further studies to investigate the correlation with environmental factors, such as elevation, slope, water type, soil type, soil salinity, geology, hillshade, (Al-Kindi et al., 2016) and solar radiation.

In addition, the results can also be used in studies to investigate the relationships between DB infestations and climatological factors such as humidity, rainfall, temperature, wind directions and speed (Payandeh, Kamali, & Fathipour, 2010). Environmental changes and socio-economic factors may also play key roles in enhancing the development, survival and spread of pests such as DB (Al-Marshudi, 2002) . In recent years, extreme weather conditions have severely affected date palm productions in Oman such as cyclone Goun in 2007, Phet in 2010, the Nanuk in 2014, and Ashobaa in 2015(Al-Yahyai & Khan, 2015). Drought, due to a lengthy rainless period and the drying up of many wells, increased water and soil salinity may also support increase and development of insects such as DB. Date palm cultivation in Oman remains a traditional human practice and farmers face many problems such as traditional irrigation, fertiliser, and application approaches (Al-Marshudi, 2002; Al-Yahyai, 2006). Biotic problems are also of great concern to growers, particularly pests such as DB (El-Juhany, 2010).

SDE emphasises this trend because it conducts confidence analysis and provides results based on a statistical technique and not just on visual interpretation of maps. For example, DB distribution and orientation (ellipse) coincides with natural features, such as mountains, valleys and dry rivers (refer to Figure 7). This may be due to quality water, quality soil, and valuable shelters supporting DB's development. Water available in fronds make palms a breeding ground for DB as well. As a result, in our next study we plan to use modern geostatistical techniques and statistic available in ArcGIS packages to look at why DBs are clustered in certain region/conditions. These techniques might help us to identify the most important geographical combinations of variables that help DB develop, prosper and migrate. Once the individual factors or combinations of factors have been identified we will then use these to develop predictive models that will be able to give us the probability of occurrence, spatial distribution and densities under different environmental, climatological and resource availability conditions. These models might be able to forecast the spatial distribution and densities of the bug under prevailing condition at the beginning of each season. These results in-turn could be used to confirm/discard previous hypotheses and generate new working hypothesis.

Identifying the potential causes of DB infestation is useful to help risk managers know where to locate their resources. Figure 7 shows an elongated ellipse of DB distribution with a particular orientation. We believe the identified patterns of DB infestation are not in part artefacts of the study area boundaries, but are genuinely based on the distribution of palm trees across the regions.

According to Blumberg (2008), DB typically avoids direct sunlight, and the density spread is enhanced by transfer of infested offshoots and by wind. This study provides useful information about hotspots in nine central governorates in northern Oman using an infestation level index for spatiotemporal risks. The results indicate that entomologists can identify infestation clusters when factoring in temporal properties such as number of adult and nymph cases occurring within a specific time frame. Spatiotemporal risk details presented in this research confirm that the use of temporal-risk and geographical analysis models, based on annual infestation level index, can produce critical datasets to better understand changes.

Furthermore, this study recommends an agricultural policy that promotes the establishment of an Intellectual Property (IP) program that implements GIS and remote sensing function tools for conducting daily or monthly assessment of seasonal DB generations (i.e. autumn and spring). This program is expected to provide improved DB surveillance systems and lead to better intervention control in Sultanate of Oman.

5. Conclusion

This study is important for palm tree health especially in Oman, because no published research exists on applying spatiotemporal analysis to detect diseases and infestations that attack palm trees. The spatiotemporal distribution of DB infestations can be linked to environmental, meteorological, climate change and human factors that promote the development and prevalence of this pest. DB develops and inhabits areas with suitable environmental, meteorological and cultural conditions. This is true for every single plant and animal species. Organisms inhabit those sites that are most suitable to their needs and survival. This study also generated data at fine scales that cover much larger areas of northern Oman than any of the previous studies. It also benefits both the government and the farmers of Oman by identifying suitable locations and optimal cultural practices for the planting of date palms and the prediction of future infestations.

Hotspot and distribution analysis results of DB infestations can inform more targeted insecticide applications. These approaches will save insecticide use, thereby lowering expenses for farmers and the government. Farmers will be better informed about DB risks and impacts. They will likely take actions earlier, thus reducing insecticide use. Spatial analysis, hotspot analysis and distribution patterns will improve knowledge about DB distribution and risk areas, which will in term support early intervention to limit damage.

MGD analysis can also be used to monitor and identify adult and nymph hotspots and their distribution in order to eliminate DB breeding sites. The results of this study create a basis for future research, especially with respect to control programs for identifying accurate locations that can be targeted when applying management techniques.

6. Acknowledgement

We thank the Unit of Cultivations Protection of the Ministry of Agriculture and Fisheries in the Sultanate of Oman for providing the annual data of Dubas Bug infestations.

7. References

Abdullah, S. K., Lorca, L., & Jansson, H. (2010). Diseases of date palms (Phoenix dactylifera L.). *Basrah J. for Date Palm Res, 9*, 40.

Ai-Leen, G. T., & Song, R. J. (2000). The use of GIS in ovitrap monitoring for dengue control in Singapore. *Dengue Bull, 24*, 110-116.

Al-Azawi, A. (1986). A survey of insect pests of date palms in Qatar. *Date Palm Journal, 4*(2), 247-266.

Al-Busaidi, M. A., & Jukes, D. J. (2015). Assessment of the food control systems in the Sultanate of Oman. *Food Control, 51*, 55-69.

Al-Deeb, M. A. (2012). Date palm insect and mite pests and their management. *Dates production, processing, food, and medicinal values*, 113-128.

Al-Khatri, S. (2004). *Date palm pests and their control.* Paper presented at the Proceedings, Date Palm Regional Workshop on Ecosystem-Based IPM for Date Palm in Gulf Countries. UAE University, Al Ain, UAE.

Al-Kindi, K., Kwan, P., Andrew, R., & Welch, M. (2016). *Impact of environmental variables on Dubas bug infestation rate: A case study from the Sultanate of Oman*. Manuscript submitted for publication.

Al-Marshudi, A. (2002). Oman traditional date palms: production and improvement of date palms in Oman. *Tropicultura, 20*(4), 203-209.

Al-Yahyai, R. (2006). *Improvement of date palm production in the Sultanate of Oman.* Paper presented at the III International Date Palm Conference 736.

Al-Yahyai, R., & Al-Khanjari, S. (2008a). Biodiversity of date palm in the Sultanate of Oman. *Afr. J. Agric. Res, 3*(6), 389-395.

Al-Yahyai, R., & Al-Khanjari, S. (2008b). Biodiversity of date palm in the Sultanate of Oman. *African Journal of Agricultural Research, 3*(6), 389-395.

Al-Yahyai, R., & Khan, M. M. (2015). Date Palm Status and Perspective in Oman *Date Palm Genetic Resources and Utilization* (pp. 207-240): Springer.

Ali, H. G. (2010). *Development of Date palm Cultivation and its Role in Sustainability of Agriculture in Oman.* Paper presented at the IV International Date Palm Conference 882.

Anselin, L., & Getis, A. (2010). Spatial statistical analysis and geographic information systems *Perspectives on spatial data analysis* (pp. 35-47): Springer.

Blumberg, D. (2008). Review: Date palm arthropod pests and their management in Israel. *Phytoparasitica, 36*(5), 411-448.

El-Juhany, L. I. (2010). Degradation of date palm trees and date production in Arab countries: causes and potential rehabilitation. *Australian Journal of Basic and Applied Sciences, 4*(8), 3998-4010.

El-Shafie, H. (2012). Review: List of arthropod pests and their natural enemies identified worldwide on date palm, Phoenix dactylifera L. *Agriculture and Biology Journal of North America, 3*(12), 516-524.

El-Shafie, H. A., Peña, J. E., & Khalaf, M. Z. (2015). Major Hemipteran Pests *Sustainable Pest Management in Date Palm: Current Status and Emerging Challenges* (pp. 169-204): Springer.

Elwan, A., & Al-Tamimi, S. (1999). Life cycle of Dubas bug Ommatissus binotatus lybicus De Berg.(Homoptera: Tropiduchidae) in Sultanate of Oman. *Egypt. J. Agric. Res, 77*(4), 1547-1553.

Garelli, F. M., Espinosa, M. O., & Gürtler, R. E. (2013). Spatial analysis of Aedes aegypti immatures in Northern Argentina: Clusters and temporal instability. *Acta tropica, 128*(3), 461-467.

Gassouma, M. S. (2004). *Pests of the date palm (Phoenix dactylifera).* Paper presented at the Proceedings of the regional workshop on date palm development in the GCC countries of the Arabian Peninsula, Abu Dhabi, 29-31 May 2004.

Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. *Geographical analysis, 24*(3), 189-206.

Griffith, D. A. (1987). Spatial autocorrelation. *A Primer (Washington, DC, Association of American Geographers).*

Howard, F. (2001). Insect pests of palms and their control. *Pesticide Outlook, 12*(6), 240-243.

Hussain, A. A. (1963). Biology and control of the dubas bug, Ommatissus binotatus lybicus De Berg.(Homoptera, Tropiduchidae), infesting date palms in Iraq. *Bulletin of Entomological Research, 53*(04), 737-745.

Jasim, H., & Al-Zubaidy, H. (2010). *Eggs Distribution of Old World Bug (Dubas Bug) Ommatissus lybicus (Derbeg) Asche and Wilson (Homoptera: Tropiduchidae) on Fronds Rows and Effect of Dust Storms on Three Varieties of Date Palm Trees.* Paper presented at the IV International Date Palm Conference 882.

Khalaf, M. Z., & Khudhair, M. W. (2015). Spatial distribution of dubas bug, Ommatissus lybicus (Homoptera: Tropiduchidae) in date palm frond rows. *International Journal of Entomological Research, 3*(1), 09-13.

Kinawy, M., & Al Siyabi, A. (2012). *Major arthropod pests of date palm in Arab countries.* Paper presented at the First Regional conference about management of date palm pests, UAE.

Kounadi, O., & Leitner, M. (2015). Spatial information divergence: Using global and local indices to compare geographical masks applied to crime data. *Transactions in GIS, 19*(5), 737-757.

Kulldorff, M., Athas, W. F., Feurer, E. J., Miller, B. A., & Key, C. R. (1998). Evaluating cluster alarms: a space-time scan statistic and brain cancer in Los Alamos, New Mexico. *American journal of public health, 88*(9), 1377-1380.

Mahmoudi, M., Sahragard, A., Pezhman, H., & Ghadamyari, M. (2015). Demographic Analyses of Resistance of Five Varieties of Date Palm, Phoenix dactylifera L. to Ommatissus lybicus De Bergevin (Hemiptera: Tropiduchidae). *Journal of Agricultural Science and Technology, 17*(2), 263-273.

Mani, A., Handoo, Z., & Livingston, S. (2005). Plant-parasitic nematodes associated with date palm trees (Phoenix dactylifera L.) in the Sultanate of Oman. *Nematropica, 35*(2), 135.

Mitchell, A. (2005). The ESRI guide to GIS analysis, Volume 2: Spatial Measurements and Statistics. Redlands: CA: Esri Press.

Mokhtar, A. M., & Al Nabhani, S. S. (2010). Temperature-dependent development of dubas bug, Ommatissus lybicus (Hemiptera: Tropiduchidae), an endemic pest of date palm, Phoenix dactylifera. *European Journal of Entomology, 107*(4), 681.

Neill, D. B., Moore, A. W., Pereira, F., & Mitchell, T. M. (2004). *Detecting significant multidimensional spatial clusters.* Paper presented at the Advances in Neural Information Processing Systems.

Ord, J. K., & Getis, A. (1995). Local spatial autocorrelation statistics: distributional issues and an application. *Geographical analysis, 27*(4), 286-306.

Payandeh, A., Kamali, K., & Fathipour, Y. (2010). Population structure and seasonal activity of Ommatissus lybicus in Bam Region of Iran (Homoptera: tropiduchidae). *Munis Entomol. Zool, 5*, 726-733.

Shah, A., Mohsin, A. U., Hafeez, Z., Naeem, M., & Haq, M. I. U. (2013). Eggs Distribution Behaviour of Dubas Bug (Ommatissus Lybicus: Homoptera: Tropiduchidae) in Relation to Seasons and Some Physico-Morphic Characters of Date Palm Leaves. *Journal of insect behavior, 26*(3), 371-386.

Shah, A., Naeem, M., Nasir, M. F., Irfan-ul-Haq, M., & Hafeez, Z. (2012). Biology of Dubas Bug, Ommatissus lybicus (Homoptera: Tropiduchidae), a Pest on Date Palm During Spring and Summer Seasons in Panjgur, Pakistan. *Pakistan Journal of Zoology, 44*(6).

Thacker, J., Al-Mahmooli, I., & Deadman, M. (2003). *Population dynamics and control of the dubas bug Ommatissus lybicus in the Sultanate of Oman.* Paper presented at the The BCPC International Congress: Crop Science and Technology, Volumes 1 and 2. Proceedings of an international congress held at the SECC, Glasgow, Scotland, UK, 10-12 November 2003.

Wong, D. W. (1999). Geostatistics as measures of spatial segregation. *Urban Geography, 20*(7), 635-647.

Wong, W., & Lee, J. (2005). *Statistical analysis of geographic information with ArcView GIS and ArcGIS*: Wiley.