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Modelling spatiotemporal patterns of dubas bug infestations on date palms in northern Oman: A geographical information system case study

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ABSTRACT

The aim of this paper is to demonstrate how Geographical Information System (GIS) can be used effectively to study infestations of Dubas bug (DB), *Ommatissus lybicus* Bergevin, in date palm (*Phoenix dactylifera* L.) 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™,[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 facilitate the allocation of resources for the treatment of infestations and allow for more effective monitoring of its influence on date palm trees.

1. Introduction

Date palm (*Phoenix dactylifera* L.), 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, and Spain, resulting in widespread damages to date palms (Howard, 2001; Blumberg, 2008; Khalaf and 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 (Hussain, 1963; Howard, 2001; Al-Khatri, 2004; Mokhtar and Al Nabhani, 2010; Kinawy and Al Siyabi, 2012; Mahmoudi et al., 2015). 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 and Al-Tamimi, 1999).

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

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The DB was first recorded in Oman in 1962. The Ministry of Agriculture and Fisheries (MAF) has made huge efforts to control its infestation. Insecticides have been evaluated for DB management by air and ground spraying (MAF, 1997; MOA, 2010; Mamoon et al., 2016). However, the most effective pesticides are banned because of their side effects (e.g., irritation) (Al-Yahyai and Khan, 2015). In addition, these methods are expensive and can have negative environmental impacts on non-target species (Hussain, 1963; Al-Azawi, 1986), in particular on natural enemies (El-Shafie, 2012; Shah et al., 2012). Furthermore, chemical control measures have had limited successes in Oman, where DB continues to pose a major challenge for the agricultural industry.

Although there are a number of studies on the biology and ecology of DB (Thacker et al., 2003; Jasim and Al-Zubaidy, 2010; Al-Deeb, 2012), 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 and Song, 2000).

Spatial clustering methods can be used to identify hotspots of affected areas. Until now, temporal dynamics 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 DB infestations 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) quantify the degree of change of their infestation levels.

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 and 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 infested date palms and nearby trees, causing up to 50% crop loss during a heavy infestation (Al-Khatri, 2004; Mani et al., 2005; Al-Yahyai and Al-Khanjari, 2008; Ali, 2010). The study area covers a size of ~114,336 km^2 and includes nine governorates. Half of the area with date palms planted is located along the coastline plain (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 and Al-Khanjari, 2008).

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 5–10 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 by counting the number of honeydew droplets from palm trees (Mokhtar and Al Nabhani, 2010).

In this study, we selected the counting of nymphs method to create a geodatabase. We classified the DB infestation levels into 4 groups (very low, low, moderate and high) in ArcGIS 10.3 as follows: very low infestation (0–5 nymphs per leaflet); low (5–7 nymphs per leaflet); moderate (8–9 nymphs per leaflet); and high infestation 10 or more nymphs per leaflet. The number of nymphs per leaflet at each potentially infested site was collected in both spring and autumn generations from 2006 to 2015. 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 and 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:

$$\overline{X}_w = \frac{\sum_i (w_i X_i)}{\sum_i w_i}, \ \overline{Y}_w = \frac{\sum_i (w_i Y_i)}{\sum_i w_i} \quad (1)$$

where $\overline{X}_w$ is the weighted mean X-coordinate, w_i is weight, $\overline{Y}_w$ 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