Current research Project: Modelling of Dubas Bug Habitat and Population Density in Oman Based on Associations with Human, Environmental and Climatological Factors

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Summary: Climatological and environmental conditions are very important in determining the distribution and survival of any species, both plants and animals, and the same applies to the Dubas bug. Understanding the distribution and affinity of the bug to variables can play a key role in mapping, control and management, including resource allocation (spray teams, field personnel, etc.).

This research will use tools and techniques available in modern spatial analysis packages, such as Geographic Information Systems and Remote Sensing, to model and develop spatial links and correlations between presence/absence/density of Dubas bugs with climatological, environmental and human factors and conditions. We will develop GIS layers that give the density and distribution of the bug infestation levels and the stress observed in the date palms, and link them with rainfall patterns, humidity, wind direction, temperature, soil salinity, irrigation practices, farming practices, etc. to investigate correlates. We will also investigate whether soil types, geology, aspect, slope, elevation and available solar radiation play any part in enhancing the development, survival and spread of the Dubas bug. We will also use combinations of some of these variables, such as the humid-thermal index (HTI) to gain an understanding of preferred environments of the Dubas bug. This research will start off by using single variables to develop correlations and then move onto more complicated predictive models and regression analysis where we incorporate all factors to investigate what combinations of factors are the most conducive to the survival and spread of the bugs.

We will use modern geostatistical techniques and statistics to look at hot spots and clustering of the bugs and investigate why they are clustered in certain regions/conditions. These techniques will help us identify the most important variables or combinations of variables that help the Dubas bug develop, prosper and migrate.

The project will also use remote sensing tools and satellite images to develop early detection techniques for the Dubas bug at broad scales. We will use satellite images to map the spatial distribution of the bug, and possibly do this on a temporal scale as well to see the directions and speed of spread. The output, especially the spatial distribution and spread images, will be used as inputs to the GIS-based predictive models.

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This project will also look at issues such as:

1- Human-related factors, such as aerial spraying. It will be of value to gather aerial and ground insecticide spraying data for the past 10 to 20 years and correlate these with current bug densities and densities of key natural enemies.

2- Cultural practices such as planting distance, irrigation, fertilization, pruning and sanitation should be also considered in any model to explain distribution and density of the Dubas bug.

3- Biotic factors such as species and densities of natural enemies (predators, parasitoids, parasites, and pathogens). Even if the environment and climate is conducive, but there is significant mortality due to natural enemies then Dubas bug densities will effectively be lower.

4- We will use modern geostatistical techniques and statistics such as Geary's Index, Morans I, Getis-Ord Gi*, Ripley's K-Function, etc. to look at hot spots and clustering of the bugs and investigate why they are clustered in certain regions/conditions. These techniques will help us identify the most important variables or combinations of variables that help the Dubas bug develop, prosper and migrate. Once the factors and 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 then could be used to forecast the spatial distribution and densities of the bugs under prevailing conditions at the beginning of each bug season. These results in-turn could be used for management purposes and for decision making as to where to direct resources for preventive action. A second, but linked, part of this project will use remote sensing tools and satellite images to develop early detection techniques for Dubas bug at broad scales. We will use images such as Quickbird (both panchromatic and multispectral) and/or the new 8-band WorldView images to map the spatial distribution of the bug, and possibly do this on a temporal scale as well to see the directions and speed of spread. We intend to use the new hyperspectral remote sensing techniques to develop early pre-visual detection of the Dubas bug. The output, especially the spatial distribution and spread images, will be used as inputs to the GIS-based predictive models.

Summary of Objectives:

1- Study the ability of using remote sensing and geographic information system to detect Dubas Bug infestation.
   - Study spectral feature of Dubas Bug infestation symptoms.
   - Study Dubas Bug infestation detection from satellite image.

2- Geospatial investigation to find the main factors which influence the spatial and temporal infestation of Dubas Bug in Oman
   - Study Dubas Bug infestation in relation to date palm trees spacing and density by remote sensing.
   - Study Dubas Bug infestation in relationship farmer practices.
   - Study Dubas Bug infestation in relation to metrological factors and environment factor.
   - Study Spatial distribution of Dubas Bug infestation in relationship to solar radiation.

3- Investigating the impacts of climate change on date palm in Oman by 2030, 2050, 2070 and 2100.

4- Identifying the reasons of why some regions in Oman are projected to become unsuitable for date palm cultivation as it could be a consequence of only one stress for date palm growth, such as wet, hot, dry, cold stress or it is the consequences of a combination of multiple stresses. Such modeling is useful in planning future strategies and minimizing economic impacts in areas that may be adversely impacted, while preparing to take advantage of new opportunities in regions that may be positively impacted.
5- Investigating the impacts of climate change on Dubas Bug distribution in Oman by 2030, 2050, 2070 and 2100.

Outline of proposed activities/Research Methodology

(i) Determining infestation levels, tree spacings and density (Remote Sensing)

Classify satellite images to extract palm crowns, then remove the centre and concentrate on the outer part of the crown. The centre of the crown remains green and is not affected by the Dubas bug. By removing the centre and concentrating on the outer part of the crown we have a higher probability of comparing impacts of Dubas bug and categorising infestation levels. The images will then be classified using unsupervised classification technique as at this stage we will not have ground truth data. Once unsupervised classification has been achieved, the Dubas bug infested crowns will be grouped into different categories based on infestation (stress) levels as detected by the satellite image. The infestation levels will later be calibrated with ground-truth data.

30 random samples from each infestation level (no/very low, low, medium, high) will be identified for collecting detailed ground truth data. Using ground truth data, we will perform supervised classification as we will know the infestation levels at the sites. The ground truth data will be used to train the algorithm and then classify the whole image. Further 50 points from each class from this supervised classification image will be used to verify the accuracy of our classification scheme. This is important as it will tell stakeholders how much confidence they can have in using satellite imagery and the methodology for broad-scale mapping and modelling of Dubas bug infestation levels.

Infestation levels will be determined by direct assessment of the insects. The most convenient way to do this is by collection of frond samples and distinguishing between newly laid eggs (this season) from those of previous seasons which did not hatch. Per-season (June; January) per farm and per tree, 3 fronds at 3 different heights (frond ages) (bottom, middle, and top will be cut, making sure the 3 fronds are from different compass directions, from each of 4 palms per each of the 4 major cultivars of the farms (e.g. Khalas, Fardh, Khasab, Naghal). This will amount to a maximum of 48 frond samples per farm. Unhatched, unparasitized new eggs (white with greenish tissues around) will be counted to determine current season densities (which predict next season infestation) in a subsample of 10 randomly selected leaflets and 10 inter-leaflet areas from each of the base, middle, and apex of each frond. Old eggs (hatched, unhatched, parasitized) on bottom fronds will be counted (based on same subsamples indicated above) once at the beginning of the sampling program to get an idea of past infestations (accumulated for past 3-5+years).

The crown information extracted will be used to calculate the density of palms per unit area; to be used as part of the GIS based spatial analysis to answer the question whether infestation levels are linked to the density of palms. The crown information will also be used to determine random systematic nature of farms. This information will be used in the GIS analysis to answer the question whether the random plants have a higher risk of infestations.

The crown information will also be used to determine row spacings. Literature mentions that those plantations that have wide row spacings have lesser likelihood of high Dubas bug infestations. The row spacings data extracted from the satellite image will help us correlate infestation levels with row spacings.

Data generated:

- Tree density
- Tree spacing
- Infestation levels
- Accuracy of infestation level
- Type of plantation (random or systematically planted)

Image fusion techniques will be used to merge the 2.5m multispectral image with the 0.7m panchromatic image to utilise the advantages of both image sets. The panchromatic image has a very good spatial resolution but lacks the multiband information that the 2.5m multispectral image provides. By using various image fusion techniques we will be able to use the strengths of both the image sets. We will compare the accuracy and distortion levels of 4 image fusion techniques: HSV, Brovey, Gram-Schmidt and Principal Component. The selected technique will then be used for the fusion of all Worldview images and all classification (both supervised and unsupervised) will be carried out using this image.

(ii) Change detection sensitivity levels over a longer time frame (Remote Sensing)

Based on the classifications of all areas covered by the images in the first part of the project, a number of different areas will be selected for more intensive spatio-temporal risk assessment studies. We will obtain as much historical images as possible for these areas and will supplement this by the following 2 years of data. We aim to build a picture over a 10 year period of infestations (say from 2004 to 2014). These multi-year images will be classified as in the first part of the project. Change detection will be analysed by standard change detection algorithms. The change detection will tell us the degree of change in the infestation levels that needs to occur before they are detected by the satellites. This is important for the development of a management and surveillance system for Dubas bug monitoring.

(iii) Visualizing and identifying hotspots (spatial patterns) (GIS)

We will use clustering techniques such as Getis Ord Gi*, Moran's I and Ripley's K function to identify and visualize the hotspots of Dubas bug infestation. For hotspot analysis we will need locations and levels of infestations of the Dubas bug. This information will be extracted from the classified satellite image. All infested levels as detected by the satellite image will be extracted and coded for different levels of infestation. The raster data will be polygonised to give polygon data as an input to the cluster analysis algorithms. Where point data is required we will use the centres of these polygons.

The hotspot analysis will give us information about those regions that have a higher risk of infestation. Based on the hotspot analysis, different layers will be created for each level of infestation. This will then be used to determine the spatial direction for each infestation level. Direction distribution (ellipsoid) method will be used to identify the direction of each risk level.

(iv) Determining spatial correlations with meteorological variables (GIS)

Based on the satellite image classification results, we will select 120 plots for more intensive studies. 30 plots will be selected from each of no, low, medium, and high infestation classes. In each of the plots we will measure the minimum/ maximum temperature and relative humidity every half an hour every day over 2.5 years. We will mount dataloggers that record data at set intervals and can be downloaded via a USB device once every 3 months. The plots will be selected based on stratification, so that we cover different soil types, rainfall regions, elevations, etc. 40 rain gauges will be installed to cover the region and data from these will be integrated to give a continuous rainfall surface over the study region. At present most of the weather stations in Oman are along the coastal regions and are not suitably located to be used for interpolation purposes.

We will use Geographically Weighted Regression (GWR) to model correlations between Dubas bug infestations and meteorological variables. The meteorological variables tested will include temperature (max, min), relative humidity (max, min), and rainfall. Relative humidity and rainfall data recorded in the field will be supplemented by data obtained from the Bureau of Meteorology and derived from satellite imagery (NOAA or Meteosat). We will correlate each infestation level with each individual meteorological variable to determine the suitable meteorological variables and range that suits the development of Dubas bugs. Then, an overall model will be created to include those variables with the highest correlations with infestation levels.

We will use the humidity and temperature measurements from each of the plots and the densities of the Dubas bug to test the significance and predictability of the Humid-Thermal index for Dubas bug distribution. Daily minimum and maximum relative humidity and temperature data will be collected and averaged on a weekly basis. Humid thermal index (HTI) will be calculated by dividing values of humidity by the corresponding values of temperature. The correlations will be worked-out between peak values of Dubas bug infestation and weekly calculated HTI. This in turn will give most favourable and least favourable windows of conditions during seasons. Conditions during those periods will provide input in the form of HTI for developing predictive models. Other than current, this study will use available historical data of Dubas bug and HTI to strengthen predictability of the model.

(v) Modelling solar radiation on monthly basis

We will use Kumar's 1997 model to calculate the potential solar radiation at each location for 12 months and will then correlate these with different infestation levels to examine if solar radiation plays a determinant role for different infestation levels in different locations during the infestation periods. A digital elevation model (DEM) for Oman will be used in this modelling. The solar radiation modelling will be done on a per pixel basis and will incorporate the effects of slope, aspect, day of the year, sun position in the sky and the impacts of shading by adjacent terrain. We believe shading will be an important factor due to the rugged terrain surrounding most of the date plantations in the wadis.

(vi) Determining spatial correlations with environmental variables

We will use GWR to model correlations between Dubas bug infestations and the environmental variables such as soil types and salinity. We will measure soil salinity in each of the 120 plots, with at least 3 readings per plot. The soil types layer will be obtained from the Ministry of Agriculture. After collecting the data of environmental variables, suitable types of soils and suitable salinity levels will be determined, and then an overall model will be created to include those variables with the highest correlations with infestation levels.

(vii) Determining spatial correlations with human relative practices

GWR will be used to model the correlations between Dubas bugs and human related practices that include irrigation practices, row spacing, density and management in terms of undercover vegetation. Firstly, row spacing and density will be extracted from the satellite images. Secondly, irrigation practices and management in terms of undercover vegetation data will be collected using a simple questionnaire. The questionnaire will be divided into 2 sections. The first section will be about irrigation practices and the second about management in terms of undercover vegetation.

(viii) WebGIS server system (eDubas)

A prototype WebGIS-based information system will be developed incorporating all the spatial and non-spatial details pertaining to Dubas bug issues. Our proposed eDubas bugs-clearinghouse will be a repository physical structure, which collects, stores, and disseminates information, data and metadata. Using this application, GIS layers will be dynamically added and/or removed during runtime and it will have basic functionalities like Zoom In, Zoom out & Pan in order to view the map with clarity. It will have options for displaying attributes like area, type of species, population and other relevant information. The query window options will help to select the theme, attribute table, and attribute values. When the query is executed, the features in the themes (e.g., wadi) that satisfy the condition will be highlighted in the Map Window. The saved queries will be used to execute the classified output based on the client's requirements. An administrator in each zone will help to maintain the server as well as the data.

A proper integration of spatial data in the GIS and the non-spatial data residing in the RDBMS will be achieved in the GIS environment through Open Database Connectivity. Care will be taken to ensure that the linkage of maps to the attribute database remains dynamic, in the sense that whenever there is a change in the attribute database, it gets reflected in the GIS. A GIS interface will be customized with ESRI ArcView® as the base, the customization environment being Avenue with Dialog Designer and ArcView Network Analyst extensions. A comprehensive custom query shell, specific to the pest-science requirement, will be built across different species attributes in the attribute database, and incorporated in the menu based graphic user interface. This will be a prototype to show proof of concept. A more detailed system can be set up later, building on the lessons and expertise of this prototype.

Figures

1- Field visit was undertaken by some of the team members and 80 sites were identified where from where initial data was collected. Figure 1 shows the sites that have been selected.
2- Analysis of historical data is currently being undertaken and some interesting patterns are being observed. Figure 2 shows different levels of infestation from 2008 to 2014.
3- All historical data was combined into one set and hotspot analysis was undertaken. This work is ongoing and is not part of Milestone 1, but is included here to show the direction of this research and overall progress. Figure 3 shows the GIS-based hotspot analysis and the regions/areas that have had the mist infections in the past.
4- Preliminary work has also been undertaken to map date plantations in northern Oman (Figure 4). This data will be further complemented by satellite image analysis at a later stage.
5- Modelling of the optimal sites of Dubas bug habitat (Figure 5).

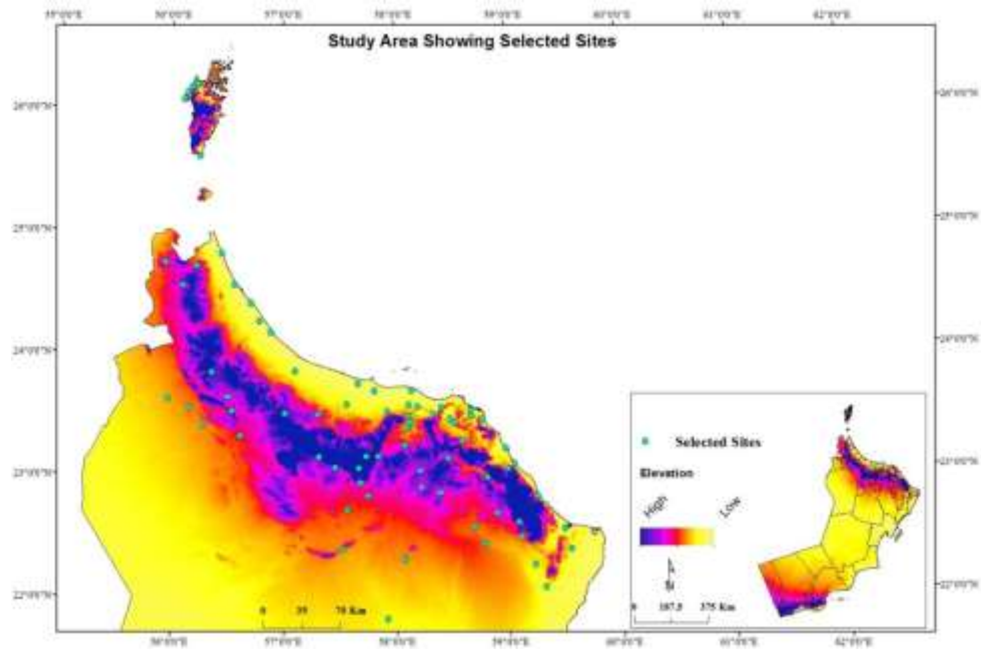

Figure 1- Study area showing selected sites

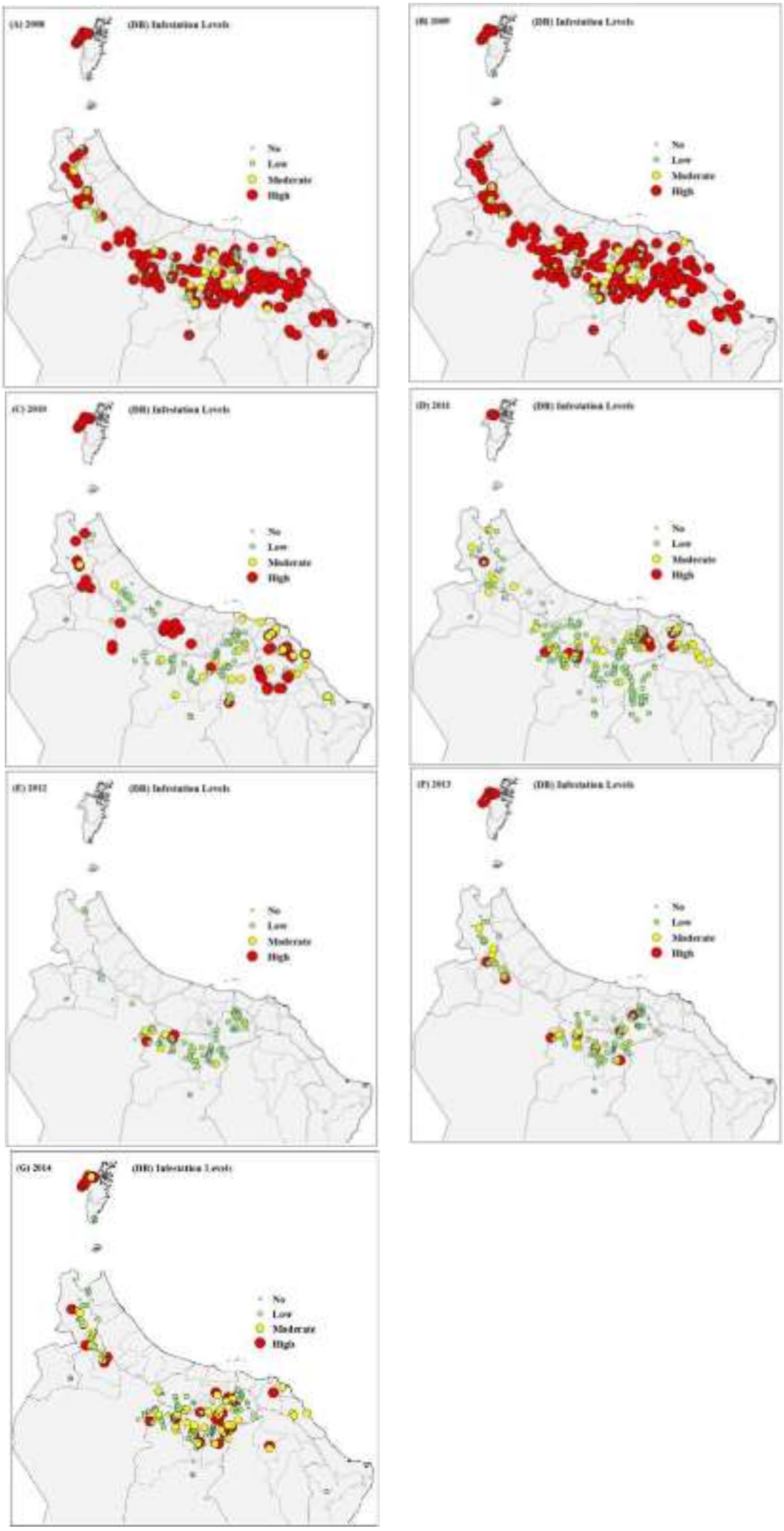

Figure 2- Density and distribution of Dubas Bug infestation levels in terms of weighted stress observed in the date palm from year 2008 to 2014. The scale is the same for all 7 maps.

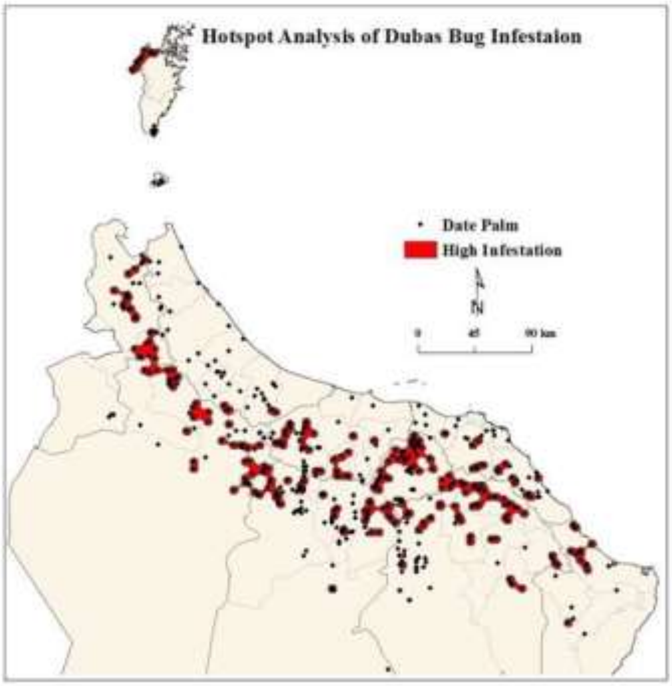

Figure 3- Hotspot analysis showing where most of past Dubas Bug infestations have been recorded.

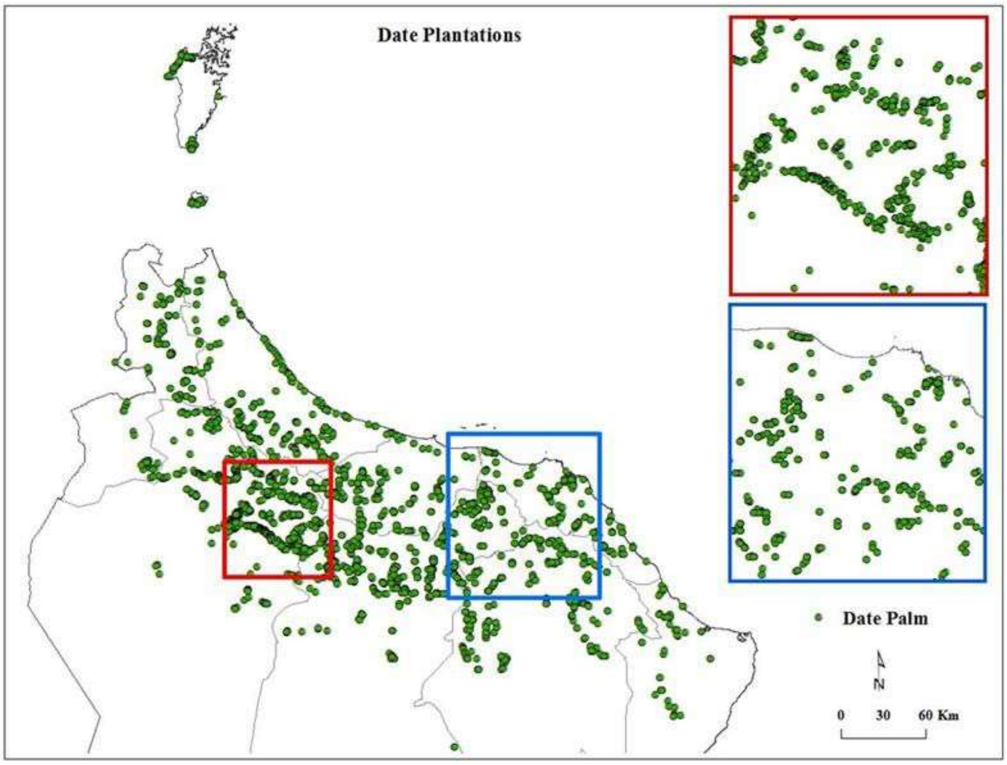

Figure 4- The distribution of date plantations in north of Oman.

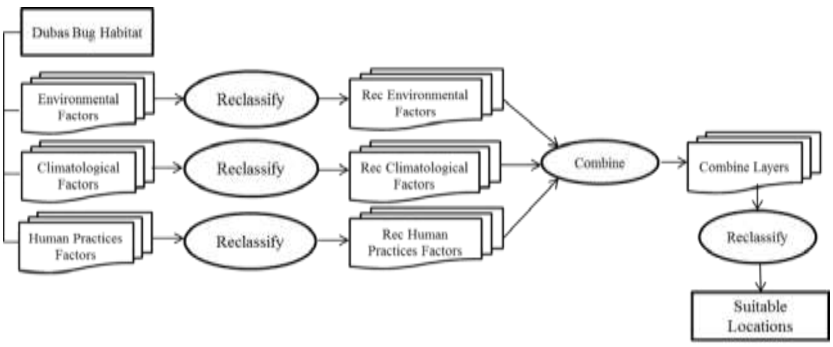

Figure 5- Model for mapping the optimal sites of Dubas bug habitat