Predicting the potential geographical distribution of the sugarcane woolly aphid using GARP and *DIVA*-GIS

Management of newly emerging pests and diseases has often been limited by the lack of forecasting systems that could predict the route(s) of spread and potential geographical distribution of the species. While the importance of the patterns of spread of invasive organisms has always been realized, the necessary analytical tools for making reasonably robust predictions are limited. In recent years however, availability of ecological and climatologic data, computational abilities to process huge data sets, and development of suitable algorithms have helped in a better understanding of the patterns of spread of the invasive species. For instance, algorithms such as Genetic Algorithm for Rule Set Prediction (GARP) and *DIVA*-GIS, are being successfully employed in a wide range of situations for predicting the spread of invasive species[1–4]. Here, we explore these two modelling approaches to predict the potential geographical distribution of a newly emerging insect pest, the *sugarcane woolly aphid* that has played havoc with crops in parts of Maharashtra and Karnataka[5].

The woolly aphid, *Ceratovacuna lanigera* Zehntner (Hemiptera: Aphididae) a serious pest of sugarcane in southeast Asia was first recorded from India on sugarcane in West Bengal[6] in 1958. This insect was first reported from Maharashtra in 2002 causing heavy loss to the sugarcane crop[5]. In less than a year, it spread southwards to several districts in Karnataka. The rapid spread of the woolly aphid has raised concerns on its possible invasion to other important sugarcane areas in Karnataka, Andhra Pradesh and Tamil Nadu. Despite the imminent economic loss, as yet there are no serious attempts to predict the potential geographical spread of the pest such that pest managers can be alerted to take up timely prophylactic measures.

In this study, we have attempted to predict the potential geographic distribution of the sugarcane woolly aphid using its current distribution and data on a range of environmental parameters. We used two computational approaches for the purpose: GARP and *DIVA*-GIS. GARP attempts to identify the 'niche' of the species defined on several dimensions of the climatic, physical, and ecological variables[7]. The principle involved is to construct a set of rules characterizing the species ecological requirements based on the limits defined by the sample geo-reference points of already known occurrence of the species. On the other hand, *DIVA*-GIS uses the BIOCLIM (Bio-climatic analysis and prediction system) to identify the areas or 'niches' to which the organism can invade based on the climatic and ecological features of the sampled data points of the known occurrence of the species[8].

The data on incidence of sugarcane woolly aphid obtained from the Karnataka State Department of Agriculture revealed that the pest was present in eight districts of the state (Belgaum, Bagalkot, Bijapur, Bidar, Bellary, Davangere, Shimoga and Haveri). The mid points (longitude and latitude) of each of the 25 taluks in these eight districts were taken as points of occurrence of the pest. The 'training layer' used the data from all the 25 points for analysis to arrive at the likely distribution of the pest[9]. The data on 13 environmental variables (for the period 1961 to 1990) used in the study were obtained from Biodiversity Research Center, Kansas University, USA. For the purpose of this analysis, a mask (area of interest) was created projecting only those districts where sugarcane was grown at least in over 1000 hectares (Figure 1). Such a mask however was not used for *DIVA*-GIS[10]. For *DIVA*-GIS we used a different set of climatic variables provided with the program. For other details and conditions used in the program, please see notes 9 and 10.

The results of GARP and *DIVA*-GIS were strikingly similar. One of the interesting predictions emerging from both the programs is that the pest is not likely to spread to most of the sugarcane areas of southern peninsula (Figures 2 and 3). For instance, results from GARP suggest that the woolly aphid is not likely to spread to Tamil Nadu, Kerala and the coastal areas. Although the pest made its appearance in adjacent parts of Karnataka and Maharashtra, it has a very low probability of spreading to eastern parts of Maharashtra and Andhra Pradesh (Figure 2). Within

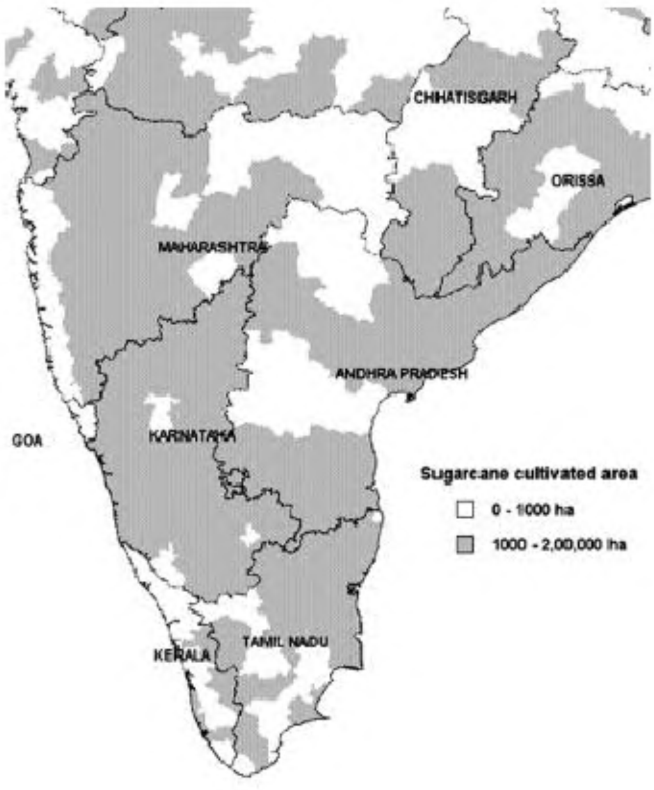

Figure 1. Map showing the regions of the country where sugarcane is grown in at least 1000 hectares in a district.

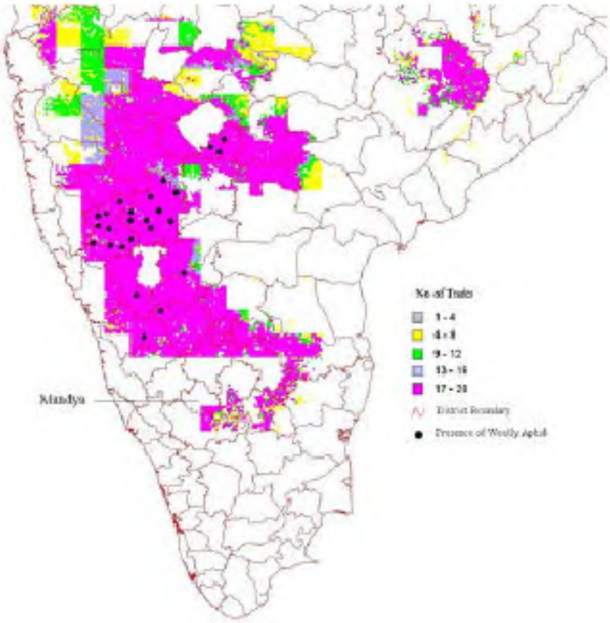

Figure 2. Map showing the areas where the sugarcane woolly aphid is predicted to be occurring by GARP. Colour is indicative of the probability of occurrence from low (yellow) to high (magenta) probability of occurrence in the sugarcane-growing areas of the country (Figure 1). The probability of occurrence was assigned depending on the number of tasks that predicted the presence of the pest in a given pixel.

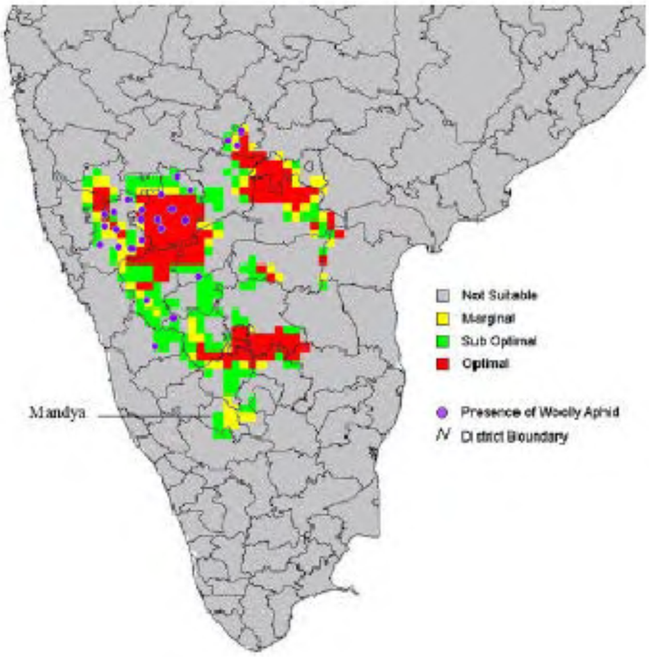

Figure 3. Map showing the areas where the sugarcane woolly aphid is predicted to be occurring by *DIVA*-GIS. Colour is indicative of the probability of occurrence from low to high (red). Note that *DIVA*-GIS does not use the sugarcane-cultivating area as the mask for predicting the distribution of the pest.

Karnataka, it is likely to occur along the transitional belt and in the northern and southern dry zones but it is less likely to occur towards south interior Karnataka (Figure 2). Further, while the southern and eastern parts of Mandya district will be conducive for the spread of this pest, the northern and western taluks of the district do not seem favourable.

The results of the simulations using *DIVA*-GIS are also identical to those obtained by GARP though it suggested a more restricted distribution with three distinct zones of occurrence for the pest. The three vulnerable zones are a) northern most parts of Karnataka and adjacent areas in Andhra Pradesh, b) parts of north-western Karnataka and adjacent areas of Maharashtra and, c) southern parts of the transitional belt of Karnataka (Figure 3). Conforming to the results of GARP, *DIVA*-GIS also suggests that Mandya is not likely to be severely affected and, Tamil Nadu and Kerala are likely to be free from the pest.

The predictions of potential distribution of the pest arrived at in this study should help in developing strategies for monitoring and managing this serious pest of sugarcane. The results of the study also offer a unique opportunity to validate the predictions by carefully collecting data on the eventual spread of the pest in the next few years. In fact our discussions with the officers of the Karnataka State Department of Agriculture indicated that the results are qualitatively upheld by the general pattern of the spread being observed by the officials (S. C. V. Reddy, personal discussions). Further, we believe that the modelling tools used in this study can be of great help in tackling several invasive pests and diseases and also in the control of invasive weeds. More importantly, such predictions would facilitate better preparedness to fight the outbreak of pests and diseases in crops.

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7. Genetic Algorithm for Rule Set Prediction or GARP (Anderson *et al.*, *Ecological Modelling*, 2003, **162**, 211–232) is a set of modules designed primarily for predicting the potential distribution of biological entities from the existing environmental and biological data on a GIS platform. The modules in GARP analyse raster-based data on the known distribution of biological entities (data on presence in an area) in an automated way and rapidly produce the distributions in unsupervised manner. The modules search for non-random associations between environmental characteristics of localities of known occurrence versus the entire study region in which we may be interested. It works in an iterative process of rule selection, evaluation, testing and incorporation or rejection to produce a heterogeneous rule-set characterizing the species' ecological requirements (Peterson *et al.*, *Science*, 1999, **285**, 1265–1267). First, a method is chosen from a set of possibilities (e.g. atomic, logistic regression, bioclimatic envelope, negated bioclimatic envelope) and it is applied to the data. Then, a rule is developed and predictive accuracy sensu (Stockwell and Peters, 1999) is evaluated via training points intrinsically re-sampled from both the known distribution and from the study region as a whole. The change in predictive accuracy from one iteration to the next is used to evaluate whether a particular rule

should be incorporated into the model (rule-set). The final rule-set, or ecological-niche model, is then projected onto a digital map as the species' potential geographic distribution, exported as an ASCII raster grid and imported into ArcView 3.1 (© ESRI, USA, 1998) using the Spatial Analyst Extension for visualization (http://biodi. sdsc.edu).

8. *DIVA*-GIS: The program generally uses a set of 15 of the available 24 climatic variables loaded with the program and most of these variables are those that are likely to affect the ecological domain of the organism (www.diva-gis.org). In this sense *DIVA*-GIS also is a niche modelling program but uses BIOCLIM (Nix, H. A., In *Atlas of Elapid Snakes* (ed. Longmore, R.), 1986, pp. 4–15, Australian Flora and Fauna series #7, Australian Government Publishing Service, Canberra) model for predicting the distribution.
9. In GARP, we performed 1000 iterations (program stop condition) and applied 0.01 convergence factor for 20 tasks. That is, within each task, 1000 iterations of the rules were tested and the best rule was stored for projection. The analysis was performed using climatic data for the period from 1961 to 1990. The layers used were annual minimum temperature, annual maximum temperature, mean minimum temperature, mean maximum temperature, vapour pressure, wetness, relative humidity, wind flow accumulation, aspect, DEM, slope and topography. After obtaining the output from each of the 20 tasks, we combined them to arrive at the final image of possible spread of Sugarcane Woolly Aphid in Southern Peninsular area; the probability of occurrence was assigned based on the number of tasks that predicted the occurrence of the pests in a given pixel. The categories accordingly were: 5–8 (tasks), very low probability of occurrence (yellow); 9–12 (tasks), low probability of occurrence; 13–16 (tasks), moderately high probability of occurrence; 17–20 (tasks), very high probability of occurrence (purple).
10. *DIVA*-GIS model was implemented with 14 variables, viz. annual mean temperature, hottest month maximum temperature, coolest month minimum temperature, annual temperature range, wettest quarter temperature, driest quarter temperature, minimum monthly diurnal temperature, average monthly diurnal temperature, annual mean precipitation, wettest month precipitation, driest month precipitation, annual precipitation range, wettest quarter mean precipitation and driest quarter mean precipitation to identify the potential geographical distribution of the woolly aphid. The program was run with the option Bioclim Classic (four groups) for identifying the optimum, sub-optimal, marginally suitable and not suitable areas. The algorithm attaches 0 to areas that are beyond 0–100 percentile for one or more variables, 1 for those within 0–100 percentile, 2 for those within 2.5 to 97.5 percentile and 3 for those within 5–95 percentile. Interestingly, even without using the mask of the sugarcane cultivating area, the model predictions were quite similar to those given by GARP. The program generated four categories of suitability, viz. not suitable (0), less suitable (1), marginally suitable (2) and optimum (3), for the organism.

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Carbon allocation in different components of some tree species of India: A new approach for carbon estimation

Vegetation plays an important role for carbon sink or source of atmospheric CO_2. During the process of photosynthesis, the atmospheric CO_2 is utilized by the leaves for the manufacture of food in the form of glucose. Later on, it gets converted to other forms of food material, i.e. starch, lignin, hemicelluloses, amino acids, protein, etc. and is diverted to other tree components for storage. It is a well-established fact that food is stored either in the roots or bole. Generally, the plants allocate more of the energy in the root system under stress conditions and in the aboveground components in normal conditions. However, different species respond in different ways for carbon utilization[1]. Here we have made an attempt to categorize the ranking responses to CO_2 by the different life forms.

In the present day scenario, the enhancement of atmospheric CO_2 coupled with the rise in temperature is the main reason behind the global climate change which has evidently raised the global mean temperature by 0.5°C during the last hundred years[2] and 0.4°C in the last 70 years for the Indian sub-continent[3]. Under such changing pattern of climatic condition there is need to classify the plant species