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Predicting Potential Global Distribution of The Black Spotted Yellow Borer, *Conogethes punctiferalis* Guenée (Crambidae: Lepidoptera) by CLIMEX Modelling

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Abstract

Conogethes punctiferalis Guenée is a serious invasive pest of several horticultural, agricultural and forestry plants and presently distributed in Asia and Australia. CLIMEX simulation was applied for *C. punctiferalis* to predict its potential geographic distribution in the world under present climate scenario. Ecoclimatic index (EI), which describes the differential climate suitability for the establishment of the pest, was assessed for different locations in the globe. The map comparisons show good agreements between simulated and present distribution of this pest, indicating that the CLIMEX model has promising potential for prediction of future distributions of this species globally. As the present pest distribution is restricted to Southeast Asia and Australia, potential areas where the pest can establish if inadvertently or via transit introduced are stated in this chapter.

Keywords

CLIMEX · Climate change · Future distribution · Potential regions · Ecoclimatic Index

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9.1 Introduction

The Black spotted yellow borer, *Conogethes punctiferalis* (Crambidae, Lepidoptera), commonly also known as castor capsule borer or durian borer is an invasive pest and currently restricted to Asia and Australia. There may be more than 20 species found in the genus, of which 7 at least may occur in Southeast Asian countries (Robinson et al. 1994). As the species number within the genus is unknown, their bioecology cannot be distinguished easily. The prediction on possible distribution of *Conogethes* has been made based on available information from all recognized species within *C. punctiferalis* species complex.

C. punctiferalis is a polyphagous pest on various crops infesting more than 30 plant species belonging to 23 different families in India (Devasahayam and Abdulla Koya 2005). Presently, it is restricted to Asia, Australia and Papua New Guinea (Fig. 9.1). In Asia, it is found in China (AQSIQ 2007), India, Indonesia, Japan, Korea, Malaysia, Taiwan, Thailand and Vietnam (Gour and Sriramulu 1992; Hang et al. 2000; Kang et al. 2002; CABI 2011). As *C. punctiferalis* can feed on broad range of host plants, its fitness differs on various host plant species (Honda et al. 1979; Li et al. 2015).

In Australia, it is a major pest on cotton and sorghum (USDA 1957). It is a major pest in North Queensland on *Nephelium lappaceum* (rambutan) and *Durio zibethinus* (durian) fruits (Astridge 2001). In Asian countries, like India and Sri Lanka, this is a serious pest of castor, tropical and sub-tropical fruits (USDA 1957), ginger and cardamom followed by *Hedycium* spp., *Alpinia* spp. and *Ammomum* spp. (Devasahayam and Abdulla Koya 2005; Shashank et al. 2015) in India. The borer *C. punctiferalis* is reported as major pest on peaches in China (USDA 1957). Yellow peach is preferred host in Japan (Konno and Shishido 1980; Konno et al. 1981; Kadoi and Kaneda 1990; Abe and Sanari 1992; Kimura and Honda 1999).

There is no evidence or published data regarding the existence of the borer in countries like Africa and the USA, but it was intercepted through international

Fig. 9.1 *Conogethes punctiferalis* world distribution map (CABI 2011)

trades (AQAS 2014). Countries like England, Wales and Netherlands have intercepted this pest while importing agricultural and horticultural commodities from the countries where *C. punctiferalis* was already established. Thus, there is a need for the identification of potential areas for the establishment of this pest as a part of pest risk analysis.

In order to predict the potential favourable regions for the establishment of *C. punctiferalis* in the world, CLIMEX *v.4.02*, a bio-climatic modelling tool and its two components, viz. 'compare locations' and 'climate matching', were used.

9.2 Compare Locations

In the present study, 'compare location' function of CLIMEX was used to generate potential distribution maps of *C. punctiferalis* for current climatic conditions with special reference to India. CLIMEX uses two constraints to estimate the potential growth and survival of a population at a given location, i.e. growth (mainly temperature and soil moisture) and stress indices (cold, heat, wet and dry stress). The values of these two indices are clubbed to generate the ecoclimatic index (EI), generally scaled between 0 and 100 (Kriticos et al. 2015). An EI close to 0 indicates location not favourable for long-term survival of a species and EI nearer to 100 as highly suitable. As EI of 100 is not possible under natural systems, in the present study, an EI of >20 was considered as highly suitable for survival and establishment of the pest, based on the current distribution and occurrence of the pest

The 'compare location' function uses meteorological database consisting of monthly long-term average climatic variables, viz. maximum and minimum temperatures, rainfall, rainfall patterns, relative humidity (RH) and soil moisture for any number of locations worldwide. An iterative process comparing the known and predicted distributions for the same region was adopted to arrive at the parameter fitting. After adjusting the parameter values, the data were used to run the model for predicting the potential distribution of the species.

$$\textbf{Ecoclimatic Index}\left(\textbf{EI}\right) = \text{TGI A} \times \text{SI} \times \text{SX}$$

where

GI A, the annual growth index, = $100\sum_{52}^{i=1} TGI_{Wi} / 52$

SI, the annual stress index, = (1−CS/100)(1–DS/100)(1−HS/100)(1−WS/100)

SX, the stress interaction index, = (1−CDX/100)(1−CWX/100)(1−HDX/100)1−HWX/100).

CS, DS, HS and WS are the annual cold, dry, heat and wet stress indices, respectively.

CDX, CWX, HDX and HWX are the annual cold-dry, cold-wet, hot-dry and hot-wet

stress interaction indices (Kriticos et al. 2015).

Climate Matching Climate matching consists of selecting a location and then looking for similar locations elsewhere with similar climatographic conditions. It simply enables the user to compare the meteorological data from different locations, with no reference to the preferences of a given species. It answers questions such as the following: Are the extreme minimum and maximum temperatures similar? Do the two locations have similar amounts of rainfall and similar seasonal rainfall patterns? Do the two locations share similar climatography?

Match climate function is used for rough assessment of the risk of a pest establishing in a new location (country, continent), with implications for quarantine and pest risk analysis (Sutherst et al. 2004). The match climate analysis can be conducted with no knowledge of the species, except that it does occur in certain locations. Thus, if there are no biological data or distribution map of the species, the match climate analysis nonetheless enables the user to qualitatively assess the risk.

Weather conditions of different locations have implications on species. For example, if user knows about a beneficial species that occurs in a given location in any country, and looking to import that species to any other country of interest, as a biological control agent, a match climate analysis can be used for selecting suitable locations. Climate match index (CMI) obtained from match climate function shows whether the climate of the destination is similar to that of the area of collection of the species and the extent of similarity in the importing country. If the analysis indicates that there is only a small area in importing country, that has a similar climate to the home location for the natural enemy to be exported, there are high risks of failure of establishment by the species in the importing country. Conversely, it can be used to identify which region of a pest species occurrence has to be targeted for prospecting activities related to biological control agents (Dhileepan et al. 2006; Robertson et al. 2008).

The composite match index (CMI) is sensitive to the number of factors included in the analysis. It uses default setting of four factors, i.e. minimum temperature, maximum temperature, total rainfall and rainfall pattern; experience has shown that a CMI value of 0.7 is a rough threshold that delimits biological reasonability. CMI values below this threshold indicate little climatic similarity (Sutherst et al. 2007).

Note that the climatic match between a ‘home location’ and a set of ‘away location’ does not accord with climatic suitability for a species. If the reference location is at the edge of a species range, a poorer match may be obtained for locations that are beyond the suitable range of the species, as well as those that are closer to the core of the species distribution.

9.3 Materials and Methods

9.3.1 Climatic Preference of the Pest, Fitting CLIMEX Parameters

CLIMEX, which includes the weather data (monthly long-term average maximum and minimum temperatures, rainfall and relative humidity) from several

Table 9.1 CLIMEX parameter values for *C. punctiferalis*

Abiotic factor	Characteristic	Value
Moisture[a]	Lower limit of soil moisture necessary for growth (SM0)	0.25
	Lower limit of optimal soil moisture for growth (SM1)	0.40
	Upper limit of optimal soil moisture for growth (SM2)	0.90
	Upper limit of soil moisture necessary for growth (SM3)	1.30
Temperature (°C)	Lower temperature threshold for growth (DV0)	8.00
	Lower limit of optimal temperature for growth (DV1)	24.00
	Upper limit of optimal temperature for growth (DV2)	26.00
	Upper temperature threshold for growth (DV3)	36.00
	Degree-day threshold above DV0 (8 °C) to complete one generation (PDD)	509.00
Stress indices	Cold stress temperature threshold (TTCS) (°C)	0.00
	Weekly rate of cold stress accumulation (THCS)	−0.01[b]
	Heat stress temperature threshold (TTHS) (°C)	38
	Weekly rate of heat stress accumulation (THHS)	0.0015
	Dry stress threshold (SMDS)	0.05
	Weekly rate of dry stress accumulation(HDS)	−0.005[b]
	Wet stress threshold (SMWS)	1.50
	Weekly rate of accumulation of wet stress (HWS)	0.002
TDD	Thermal degree-days for the development	509

[a]Moisture parameters were in units measuring the proportion of soil moisture-holding capacity
[b]Indicates the stress factor

meteorological stations located worldwide from 1931 to 1960, was used for the study. In order to overcome the spatial limitation of the limited meteorological database, a 10° grid of long-term average climate surface variables for the world terrain was used (New et al. 1999).

Iterative parameter fitting was used to develop the CLIMEX model for *C. punctiferalis*. The native range, relative abundance and seasonal phenology in India, other Southeastern Asia and Australia were used to infer climatic requirements. The adjusted parameter values were then visually validated against the reported distribution of *C. punctiferalis* around the world. In this process, the parameter values were compared favourably with the observed native distribution as summarized in Table 9.1.

Growth Indices The growth indices (on a scale from 0 to 100) indicate how favourable each location is for population growth; they were calculated weekly and annually after Sutherst and Maywald (1985).

Temperature The temperature parameter values for *C. punctiferalis* were initially inferred from available data (Bilapate and Talati 1978).

Threshold Heat Sum (PDD) The minimum thermal accumulation necessary to complete a generation (the sum of degree-days above DV0) was set at 509 degree-days for *C. punctiferalis* (Du et al. 2012).

Moisture and stress indices (cold, heat, dry, wet) were also iteratively adjusted so that the modelled distribution of *C. punctiferalis* exactly matches the present distribution of the pest. Soil moisture parameters in CLIMEX are calculated proportionally from the plant-available water capacity within the effective rooting zone. The irrigation function in CLIMEX was not used in the present context.

Stress Indices The stress indices indicate the limited population growth during unfavourable seasonal conditions. The annual stress values, on a scale from 0 (no stress) to 100 (lethal conditions), were calculated by the weekly value multiplied by the number of weeks subsequent to the stress first exceeding zero (Sutherst et al. 2007).

9.4 CLIMEX Model Matching

Climate Matching In addition to compare locations, climate match function of CLIMEX was also used by taking Hyderabad (17.37°N 78.48°E, 505 m MSL) located in Telangana state of South India, as 'home' location. This is one of the important regions with severe incidence of *C. punctiferalis*. In this region, it is a major pest on castor, pomegranate, grapes and other fruit and field crops. For predicting the favourable climatic conditions for the establishment of *C. punctiferalis*, climatic conditions of "home" location were compared with other regions of the world ('away locations'), and the climate match model was run using base climate data for the years 1961–1990. The data was obtained from CliMond (Kriticos et al. 2012). The resulting modelling output was mapped as climate match index (CMI) with different per cent match. In general, CMI of 85% and above is considered as a good match with the 'home location', favouring the establishment of the pest species.

9.5 Results and Discussion

Climatic Preference of the Pest Ecoclimatic index (EI) obtained through compare location function indicated the favourable regions for *C. punctiferalis* in all the continents except Antarctica and isolated patches in different continents as shown in the Fig. 9.2. The map denotes the favourable EI for the pest, wherein regions depicted in shades of red are more suitable for the pest compared to the regions with blue shades. The potential areas for the establishment of *C. punctiferalis* are presented below.

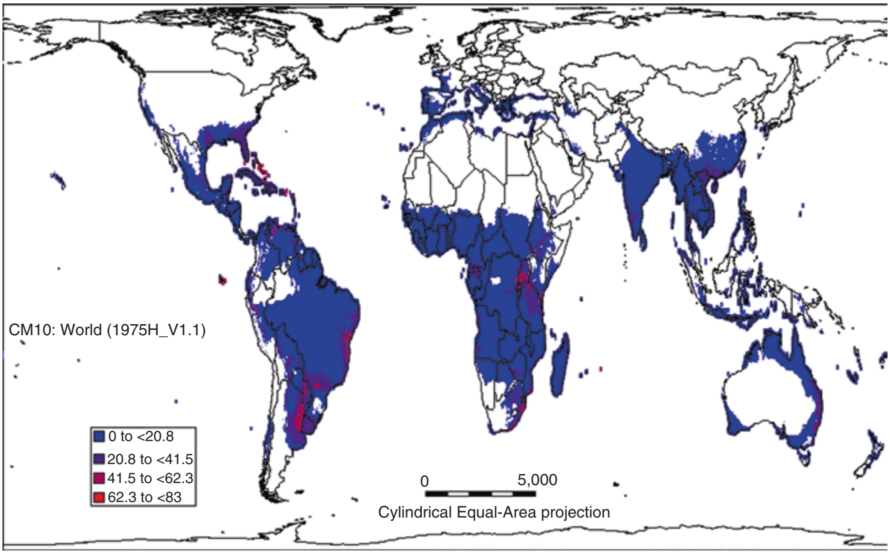

Fig. 9.2 Potential favourable regions for *C. punctiferalis* establishment based on ecoclimatic index values

North America Southeastern states of the USA like North Carolina, South Carolina, Florida, Georgia, Alabama, Luciana, Mississippi and Texas and western parts of the USA like California are favourable for the borer pest. Other countries like Mexico, Guatemala, Nicaragua, Cuba and Puerto Rico are also favourable for the pest occupancy and damage to cultivated crops. However, northern and eastern USA are not suitable for this pest establishment.

South America Major portions of South America are favourable for the pest establishment except southern and south western parts like Argentina, Chile and parts of Peru. Entire Brazil is favourable for the pest, *C. punctiferalis*, except state of Parana and Sao Paulo. Similarly the zones in southern Colombia, northern and north eastern parts of Peru and north-western parts of Brazil, i.e. State of Amazonas, are not favourable for the establishment of the pest.

Europe Western parts of Spain, Palma, Portugal, western and southern parts of France, coastal region of Italy, Crose, Sardegna, Sicilica, Malta and Greece are favourable for the pest. Parts of southern Ukraine, Moldova and parts of Romania are also favourable.

Middle East Major portions of the Middle East are not favourable for the pest, *C. punctiferalis*. However, southern parts of Yemen and south western parts of Iran are favourable for pest establishment and population development under favourable weather conditions and presence of preferred food plant.

Asia South East Asia is highly favourable for establishment of the pest embracing India, southern parts of China, southern Nepal, Bhutan, Sri Lanka, Vietnam, Thailand, Myanmar, Malaysia and regions like Indonesia, the Philippines, northern Pakistan and eastern parts of Afghanistan. The above countries share almost the same climatography and cropping situations.

Entire India is suitable for the establishment of pest, *C. punctiferalis*, except north-western parts of Gujarat, Rajasthan, Srinagar and sub-Himalayan region. However, north eastern states are also favourable for the pest infestation. All the southern states like Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Goa and eastern states like Orissa, West Bengal and Bihar provide favourable conditions for establishment of the pest and its proliferation.

Australia An analysis of pest and population growth factors for *C. punctiferalis* revealed that **c**oastal regions of northern, eastern, southern, south western parts of Australia were also found favourable for pest establishment and population development. Obviously, these areas also have host plants like cotton, maize, sorghum and temperate fruits like peach, pear, apricots and plum and in some parts forest trees that the pest prefers to feed and continue generations. The growth index reveals wide fluctuations in growth ranging from 0.2 to almost 1, the peak. Monthly rainfall pattern shows fluctuations from no rains to 50 mm.

9.6 Climate Matching

When validation of climate matching model was tested within India for the borer, Maharashtra, Gujarat, parts of Uttar Pradesh and in general west part of India showed a good match. Crops like castor and arid tropical fruits are extensively grown in these regions. The area also enjoys four seasons with varying climatographic conditions. The borer, *C. punctiferalis*, completes 6–7 generations provided preferred host plants and favourable weather conditions prevail.

Outside India, for the borer, Myanmar, Malaysia, Thailand, Vietnam, North Australia and South East Asian countries showed a good match. These are the countries where durian, rambutan, sour sop, litchi, teak, etc. are the major host plants. The borer completes 6–7 generations and incurs heavy yield losses in fruit crops. From these regions fruit crops are also exported to other countries. Therefore, monitoring *Conogethes* populations in these countries is crucial.

Based on the CMI, highest similarity between Hyderabad (home) was observed in the following region of the world (Fig. 9.3). Within India, parts of states, viz.

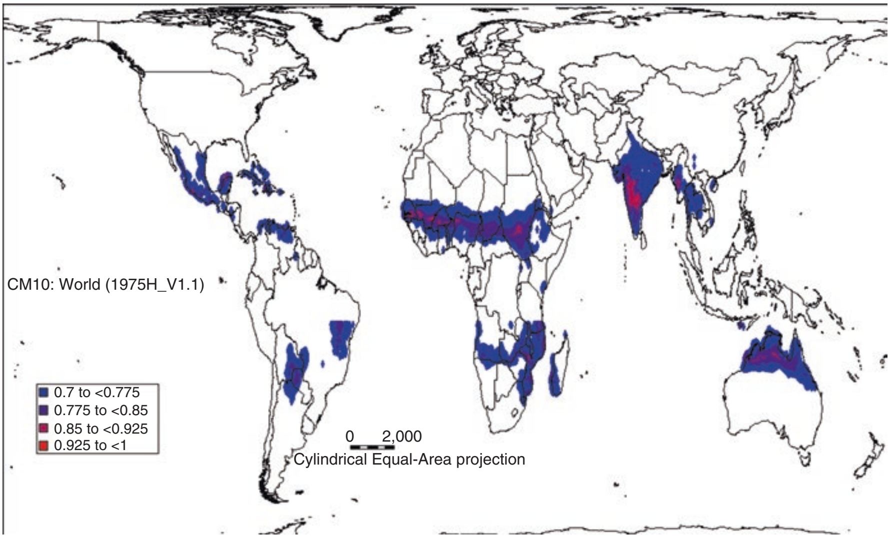

Fig. 9.3 Potential favourable regions for *C. punctiferalis* establishment based on Climate Match Index

Maharashtra, Karnataka and Gujarat, showed highest similarity (>85%) with home location. Outside India, Burma, Malaysia, Thailand, Vietnam in Southeastern Asia, Northern territories of Australia, parts of Central America, South America (parts of Brazil and Argentina) and central and southern African countries are also found similar to the home location (Hyderabad).

9.7 Validation of the Models

In contrast to the growth promoting factors, the stress factors for population growth of *C. punctiferalis* were also examined. The three major stress factors considered are dry and wet conditions, cold and hot stress factors and rainfall. The depicted patterns of dry and wet stress factors and hot and cold stress factors show wide fluctuations and extremities that are unfavourable for the borer, *C. punctiferalis*. Under these wide fluctuation conditions, the pest cannot establish, grow and develop populations. Areas experiencing such conditions are not suitable for the borer growth and population build-up. Similarly, prolonged dry conditions or no rainfall period is unsuitable for borer population to grow. Such unsuitable areas include northern and eastern USA, desert areas and equatorial parts of Africa and a large portion of the Middle East, where neither the weather conditions nor suitable host plants for the borer occur. In such areas, pockets or patches may provide favourable conditions for the borer, *C. punctiferalis*. In such patches, the shoot and fruit borer undergoes only 2–3 generations a year. For example, in some parts of China, only 2–3 generations of *C. punctiferalis* are recorded (FAO document 2007).

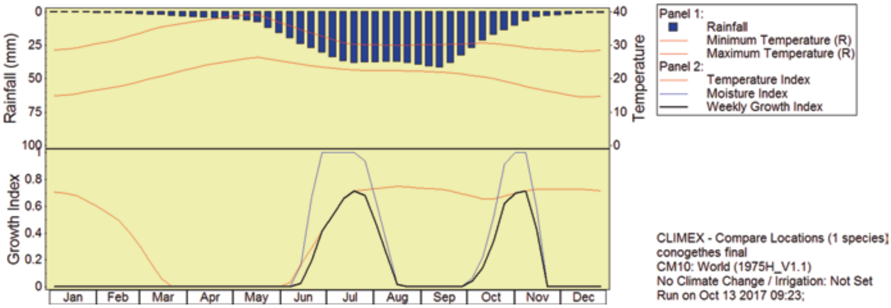

Fig. 9.4 Weekly growth index of *C. punctiferalis* at Hyderabad, South India

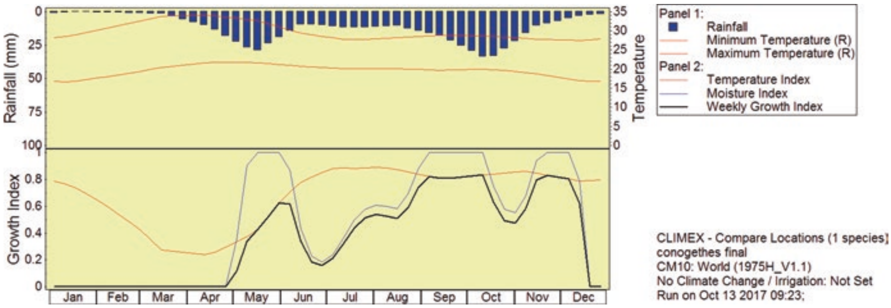

Fig. 9.5 Weekly growth index of *C. punctiferalis* at Mysore, Karnataka, South India

The annual fluctuation in the abiotic factors in Hyderabad (India) is depicted in Fig. 9.4. In Hyderabad, annual temperature fluctuates from a minimum of 15–27° C to a maximum of 30–39° C. Rainfall pattern shows fluctuation between no rainfalls to 50 mm. Generally Hyderabad has warm, dry arid conditions, and the borer is active from June to August and October to November. Custard apple, ber, pomegranate, grapes, guava and other arid fruits form major host plants for the borer, *C. punctiferalis*, in this region. Areas in other parts of India with closely related climatic conditions may favour the pest establishment provided hosts are available.

CLIMEX output revealed, in Mysore region of Karnataka (12.2958° N, 76.6394° E), the weekly growth index was observed highly favourable from May to December and is coinciding with the higher temperature index and moisture index. This has been validated through the number of generations of *C. punctiferalis* from the adjoining locations like Bengaluru (12.9716° N, 77.5946° E). The positive weekly growth index from May to mid-December indicates the favourable weather conditions for the pest supporting at least five generations/year (Krishnamurthy et al. 1989). This figure indicates the favourable abiotic factors promoting the development of the pest, i.e. moisture, temperature and weekly growth index (Fig. 9.5).

On the contrary, In Rampur region of Madhya Pradesh (24.5095° N, 81.0577° E), the stress factors played an important role in suppression of the establishment of

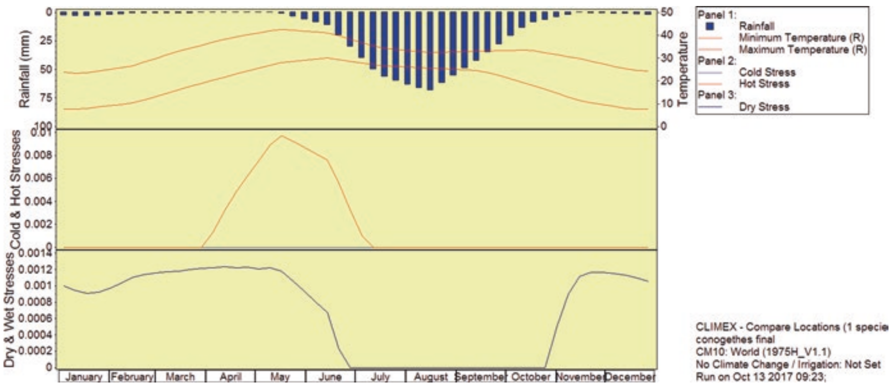

Fig. 9.6 Stress index of *C. punctiferalis* at Rampur, India

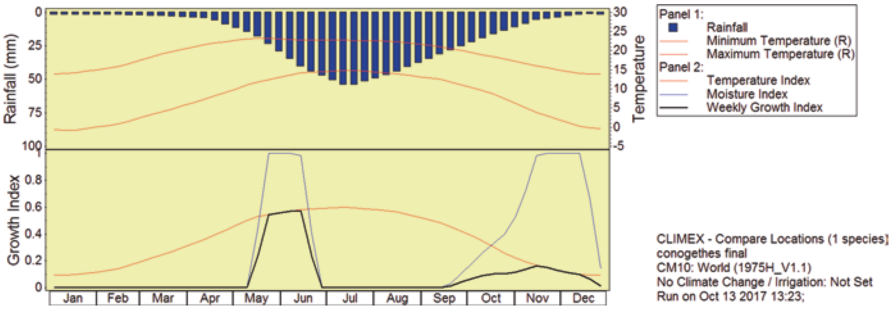

Fig. 9.7 Weekly growth index of *C. punctiferalis* in China

the *C. punctiferalis* indicated by lower EI. The stress factors (Fig. 9.6), viz. hot stress during April to July and dry stress during the months of January to June and mid-October to December, made the climate suitable only during August to October resulting to lower EI. These adverse climatic conditions in this region may not support the establishment of the pest even when the hosts are available.

Current analysis showed that in China *C. punctiferalis* can complete 2–5 generations during May to June and again during September to December (Fig. 9.7), which is validated with the observations made by Yang and Shaw (1962) who also reported 2–5 generations/year from China.

9.8 Match Climate Output

The CMI with reference to Hyderabad (home) for the rest of the world is depicted in Fig. 9.8. Amdapur located in the Nizamabad district of Telangana state in India (18.6290° N, 77.9325° E) is considered as 'away' location, which showed similar

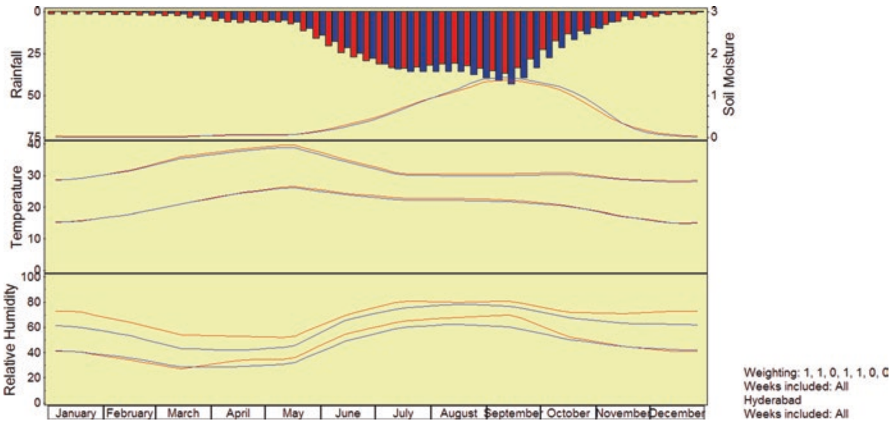

Fig. 9.8 Abiotic factors in Amdapur similar to Hyderabad which showed CMI of 0.93–1

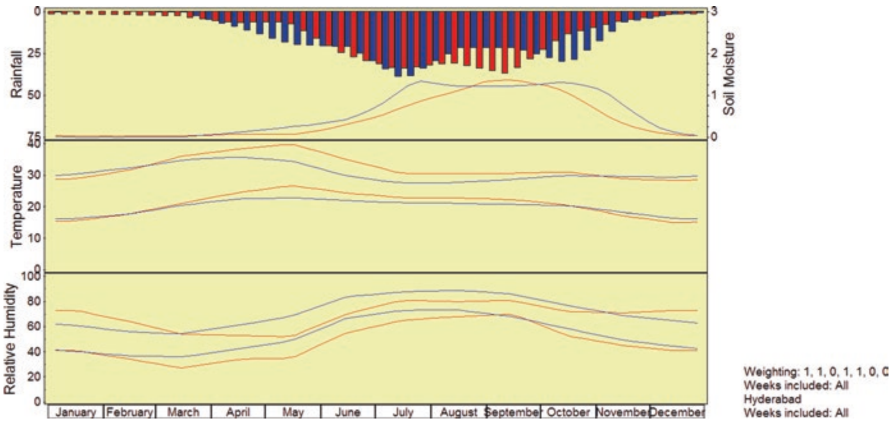

Fig. 9.9 Abiotic factors in Haveri, Karnataka, South India

CMI as 'home' location, i.e. Hyderabad with a CMI of 0.93–1 (Fig. 9.8), where favourable climatic conditions are suitable for the establishment of *C. punctiferalis*, provided suitable hosts are available. Thus, locations spread over in different parts of the globe are more suitable for *C. punctiferalis* attack.

However, Haveri (away), located in Karnataka state (14.6610° N, 75.4345° E), is compared with the Hyderabad (home) location, and it showed lower CMI of 0.7–0.77 with home location (%) and thus may not be suitable for the establishment of the pest (Fig. 9.9).

Keeping in view the importance of pest risk analysis as a part of plant quarantine measures, CLIMEX can be a prominent tool for guiding identification of potential areas for the establishment of the borer pest, and importing countries can monitor whether the exporting materials are from the pest free areas. As there are several potential areas for the establishment of *C. punctiferalis*, this can help partly PRA for importing countries of agri-horticultural commodities.

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