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CLIMEX BASED SPATIO-TEMPORAL ANALYSIS FOR PREDICTING THE NUMBER OF GENERATIONS OF *SPODOPTERA LITURA* (FABRICIUS) (LEPIDOPTERA: NOCTUIDAE) UNDER CLIMATE CHANGE SCENARIO

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ABSTRACT

Expected number of generations of *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae), a polyphagous pest on several agricultural and horticultural crops was assessed for both the present and future climate change scenario (A1B) for India using CLIMEX, a bioclimatic modeling software. Predictions were done for two future time frames (2030 and 2080) as projected by Intergovernmental Panel on Climate Change (IPCC). The pest is expected to attain one or two additional generations in most parts of the country by 2080 compared to the base year (1975). A tukey's test indicated that the number of generations are lower in baseline (10.6 ± 0.67) compared to the predicted scenarios in 2030 (11.5 ± 0.68) and 2080 (12.7 ± 0.68) time frames. There was statistically significant differences between number of generations during baseline compared with 2030 ($p = 0.014$) and 2080 ($p = 0.000$) and between 2030 and 2080 time frames ($p = 0.001$). The present findings were validated using available literature regarding number of generations possible for the pest.

INTRODUCTION

The tobacco caterpillar, *Spodoptera litura* (Fabricius), (Lepidoptera: Noctuidae) is a polyphagous pest, damaging economically important crops like tobacco, castor, cotton, soya bean and groundnut throughout tropical and temperate Asia, Australia and pacific islands (Dhir *et al.,* 1992, EPPO, 2013, Patil *et al.,* 1996, Gadhiya *et al.*, 2014, Patil *et al.,* 2015) and also damages various horticultural crops like chilli, tomato, okra *etc,* apart from other crops (Cheema *et al.,* 2004; Kaur *et al.,* 2010, Armes *et al.,* 1997) inflicting a wide range of damage. The pest remain active from end of July or mid of August to October coinciding with warm and humid climate and peak reproductive potential period, causing 26-29 per cent yield loss (Punithavalli, *et al.,* 2014). Insects are *poikilothermic* and their development is depending on the external temperature. Thermal Degree-Day based prediction models are used for predicting number of generations of various pests. CLIMEX, a bioclimatic model is a widely used application in illustrating the potential distribution of flora, fauna, crop pests and their natural enemies under climate change scenarios and also for assessing number of generations of the pests (Sutherst and Floyd, 1999; Shabani *et al.,* 2012; Senaratne *et al.,* 2006; Parsa *et al.,* 2012). Climate change may influence the pest in terms of increase in development rates, physiology, abundance, phenology, reproductive potential, overwintering survival and number of generations and distribution of the insect pests (Lastvka, 2009, Ayres and Lombardero, 2000). Past and potential displacements of insect distributions in response to climate change have received considerable attention and a number of investigators have proposed that significant warming trend would favor insects (Anantha krishnan, 2007). The present work was aimed to assess the potential impact of climate change on the spatial and temporal distribution of *S. litura*, in terms of number of possible generations, comparing the climatological normal from 1961–1990 (centered at 1975) with two future timelines, 2030 and 2080 using CLIMEX. Subsequently, this model was used to illustrate *S. litura* potential distribution using a Global Climate Model (GCM), CSIRO-Mk 3.0 (Commonwealth Scientific and Industrial Research Organisation, Australia) with the A1B (Anthropogenic emissions of CO_2, CH_4, N_2O and sulphur dioxide) storyline of IPCC-SRES (Intergovernmental Panel on Climate Change - Special Report on Emission Scenarios) (IPCC, 2007). Temperature is the main factor among all the known environmental factors affecting insect growth and reproduction due to their *poikilothermic* nature (Zhang, 2002). With the rise in temperatures due to climate change insects are going to have more number of generations, provided the temperature range is within higher and lower thresholds. In the present study the objective was to assess the impact of climate change on the number of generations of *S. litura* with particular reference to India through Thermal Degree Days (TDD) using CLIMEX, a bioclimatic modelling tool.

MATERIALS AND METHODS

Time frames

Prediction of potential number of generations of *S. litura* in India was assessed using CLIMEX based projections of temperature increase in two future time frames, 2030 and 2080 as against the present climate based on the base year data of 1975 (average of 1960-1990) for A1B Scenario of climate change in India (IPCC-TGCIA, 1999, Kumar *et al.,* 2006).

Softwares' and parameter settings

Lower and upper threshold temperatures of 10.5° and 37°C and thermal degree unit requirement for egg-egg development for *S. litura* (551.20 per generation) was used (Rao *et al.,* 1989). Based on thermal requirements, risk maps indicating the potential number of generations of *S. litura* per year was calculated for different parts of India for each scenario using CLIMEX software. Subsequently, the maps were incorporated into DIVA-GIS software for suitable contrast color codes corresponding to number of generations. A brief description of both the software's is given below:

CLIMEX

This is a bioclimatic modeling tool widely used in illustrating potential distribution of flora, fauna, crop pests and their natural enemies (Sutherst *et al.* ,1999; Senaratne *et al.*, 2006; Shabani *et al.,* 2012). Based on the data obtained from the literature, the CLIMEX generated risk maps were obtained for A1B Climate change Scenario for the time frames of 2030 and 2080 as per Sutherst *et al.* (2007) and Sridhar *et al.* (2014).

DIVA-GIS software

It is a free and open source Geographic Information System (GIS) to map species distribution (Ganeshaiah and Uma Shaanker, 1998). It has an Ecological Niche Modeling tool which can be used to predictive modeling (it uses Bioclim and Domain algorithms and the Eco-crop model). Climatic Envelope *i.e.,* broad abiotic thresholds required for the target pest *S. litura* were assessed using this software (Fig. 1).

Data analysis

Differences in number of generations among the three time frames obtained from CLIMEX were tested by one-way analysis of variance (ANOVA). Based on the significant differences detected, multiple comparisons were performed using Tukey's test (Tukey, 1949).

Homogeneity of geographical locations *Vs S. litura* generations

Dendrogram and distance matrix were performed by developing SAS codes using SAS V9.3 for number of generations of *S. litura* for both current climate and future climate change situations, with a view to know homogeneity of the geographical locations in the world in which *S. litura* was already recorded with particular reference to number of generations (Rao *et al.,* 2015).

Validation of the model

The validation of the prediction model was done based on available literature on number of generations of *S. litura* reported from different parts of India and outside for the base year 1975 (average of 1960-1990). Results obtained from two different studies (INGEN and UCIPM software) were compared with the results obtained in the present study, using CLIMEX. The earlier studies used for comparison include three locations *viz.,* Bengaluru, Kalyani and Ludhiana representing southern, eastern and north Indian regions using UC IPM online software (www.ipm.ucdavis.edu/WEATHER/index.html) (Sridhar *et al.,* 2014) and Seven locations *i.e.,* Jalgaon, Raichur, Kadiri, Bhubaneshwar, Tirupathi, Hayathnagar and Jagityal by using INGEN (ß-version) (Rao *et al.*, 2014) (Fig. 2).

RESULTS AND DISCUSSION

The climate change mediated pest risk maps generated using CLIMEX based on the TDD (Thermal Degree Days) describes the relative climatic suitability for the growth and multiplication of the pest in terms of expected number of generations in different locations. *S. litura* was able to establish and persists in most parts of India. Increase in temperatures raised through climate change is expected to accelerate the development of insects resulting in increase of number of generations of the pest. In the base line climate, the areas with more number of generations were observed in southern India barring a few locations in Karnataka. A progressive reduction in the number of generations in the areas from central to northern India is observed (Fig. 3). In comparison to the current situation, the pest is expected to have more number of generations especially in the southern parts of the country by 2080 (Fig. 4 & 5, Table 2). The results showed statistically significant difference in the number of generations between the scenarios as determined by one-way ANOVA ($F (2, 27) = 24.97$, $p = 0.000$). A Tukey's test revealed that the number of generations was statistically significantly lower in baseline (10.6 ± 0.67) compared to 2030 (11.5 ± 0.68) and 2080 time frame (12.7 ± 0.68). There was statistically significant differences between baseline compared with 2030 ($p = 0.014$) and 2080 ($p = 0.000$) and between 2030 and 2080 time frames ($p = 0.001$) in terms of supporting number of generations of the pest.

Homogeneity of geographical locations Vs *S. litura* generations

Dendrogram and distance matrix were performed through SAS V9.3 for number of generations of *S. litura* and compared for the homogeneity of the geographical locations. The results showed five distinct clusters in terms of their homogeneity and distinctness. The results also revealed a clear-cut clustering

Table 1: Parameters used in CLIMEX model for the development of *S. litura*

Temperature parameters	Mnemonic	Value
Limiting low temperature	DV0	10.5°C
Lower optimal temperature	DV1	27°C
Upper optimal temperature	DV2	32°C
Limiting high temperature	DV3	37°C
Degree-days/generation	PDD	551

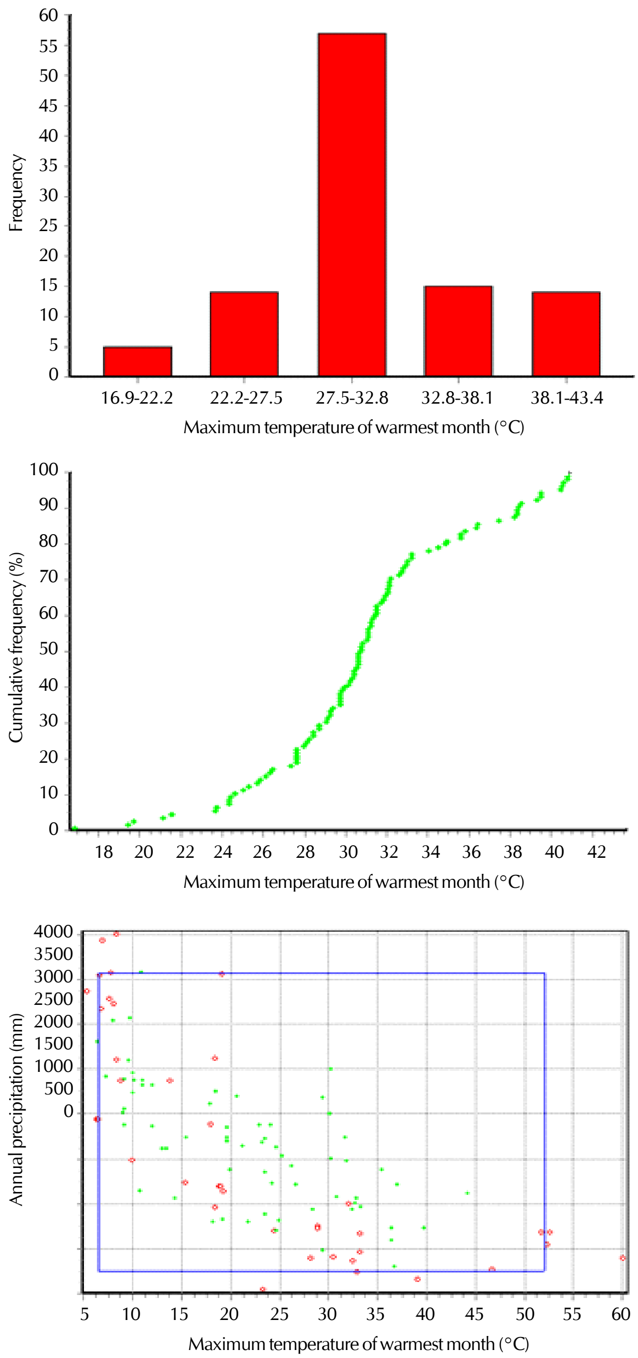


Figure 1: Climatic envelope obtained from DIVA GIS for *S. litura* from 117 locations

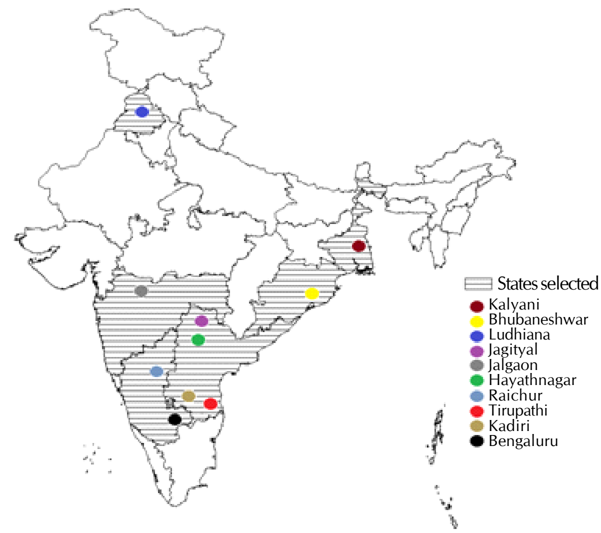


Figure 2: Locations included for comparison of *S. litura* generations

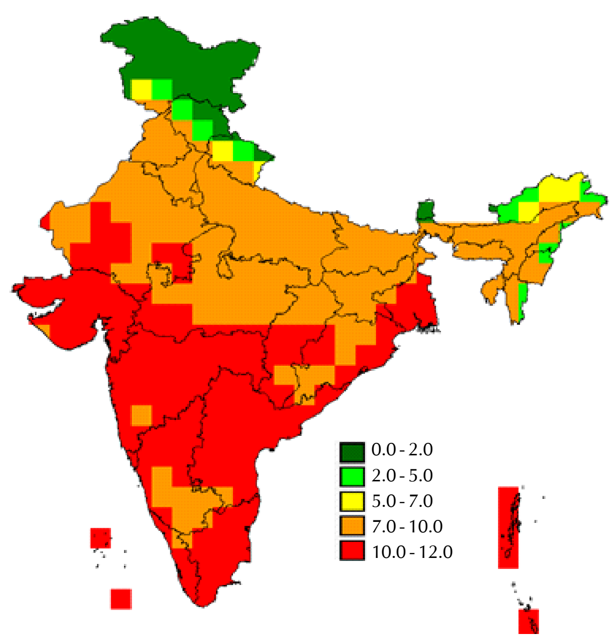


Figure 3: Potential number of generations of *S. litura* in India

of the geographical places coinciding with similar climate zones and number of generations of *S. litura*.

The present findings of increase in number of generations of *S. litura* in India signify the impact of temperature on its development and survival wherein the expected increase in temperature would turn many regions suitable for the establishment of the pest provided the host is available (Kiritani, 2007; Awmack *et al.*, 1997; Kang *et al.*,2009). Many insects alter their developmental rate, or even suppress a particular developmental stage, to cope with environmental conditions differing from place to place and time to time (Bae *et al.*, 1997; Danks, 2002), necessitating country wide projections inclusive of different agri-horticultural regions in India (Khan *et al.*, 2009; Hebbar *et al.*, 2013; Kumar and Aggarwal, 2013; Soora *et al.*, 2013). Consequently, the differences in temperature and subsequent availability of Thermal Degree Days between the localities are more likely to affect the number of generations of the pests, and may be responsible for the differences in the projections between the regions. In the present predictions using CLIMEX, *S. litura* populations in most parts of Andhra Pradesh, Tamil Nadu and parts of Karnataka, Maharashtra, Gujarat, isolated pockets in Orissa and Kerala are expected to have 11-12 generations/annum by 2080.

However, the cold temperate weather conditions of most parts

Table 2: Projected number of generations of *S. litura* in different parts of India

Number of generations	Areas with different generations of *S. litura*	
	Time frame 2030 (Fig. 4)	Time frame 2080 (Fig. 5)
0-2	Most parts of Jammu and Kashmir, Himachal Pradesh and Uttarakhand	Most parts of Jammu and Kashmir, Himachal Pradesh and Uttarakhand
5-Feb	Parts of Jammu and Kashmir, Uttarakhand, northern parts of Arunachal Pradesh, Himachal Pradesh and complete Sikkim.	It is expected to increase towards north of Jammu and Kashmir, Himachal Pradesh, northern parts of Arunachal Pradesh and complete Sikkim.
7-May	Parts of Jammu, northern parts of Arunachal Pradesh and Manipur, southern parts of Nagaland and north eastern parts of Tripura.	Parts of Himachal Pradesh, very few locations in the southern Nagaland, northern Manipur and parts of north eastern Tripura is expected to show 5-8 generations of the pest.
10-Jul	Northern Punjab, southern Himalaya, most parts of Uttarakhand, Assam, Meghalaya and Manipur, southern parts of Arunachal Pradesh and northern parts of Nagaland.	Parts of Jammu, Uttarakhand, Arunachal Pradesh, fewer parts of Assam, Meghalaya and Manipur.

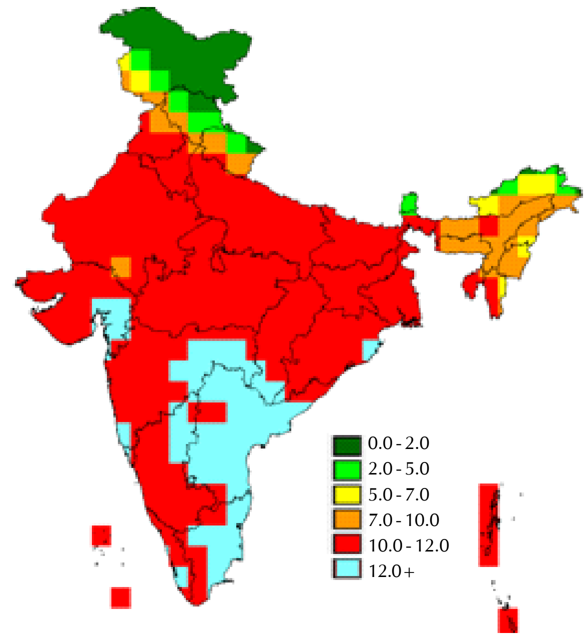


Figure 4: Projected number of generations of *S. litura* for time frame 2030

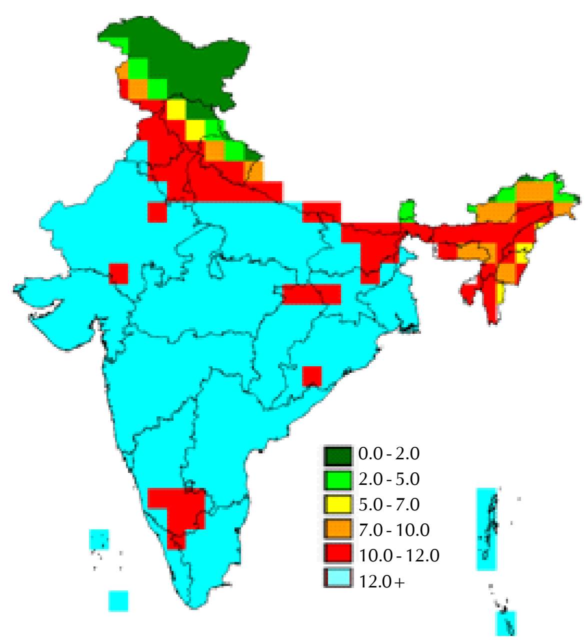


Figure 5: Projected number of *S. litura* generations for time frame 2080

of Jammu and Kashmir, Himachal Pradesh, Uttarakhand and parts of Arunachal Pradesh are restricting the increase in number of generations of the pest all through the time frames.

Based on the field observations of the trap catch from Bengaluru, the number of generations were assessed assuming each peak as starting of one generation. Similar studies were done earlier by Li *et al*. (2013) for predicting development based on temperature in *Athetis lepigone***.** Therefore pest management measures in the areas predicted to be vulnerable

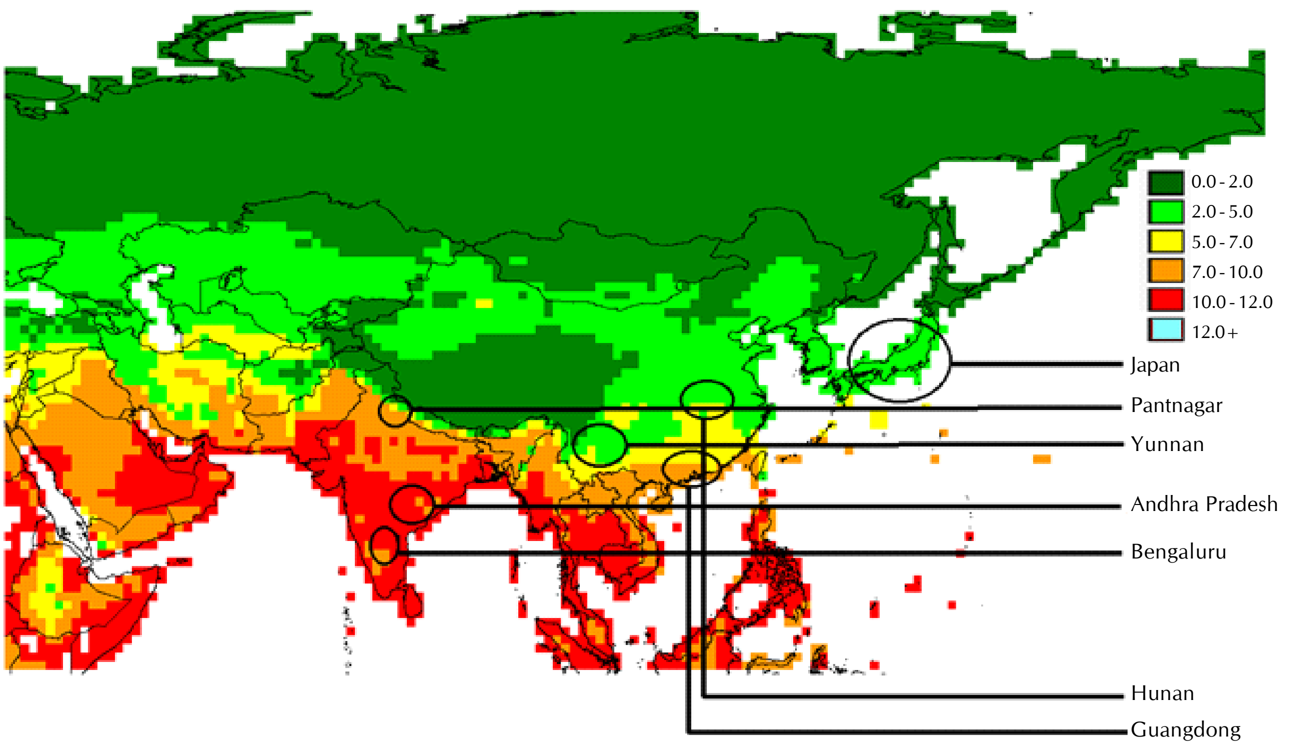


Figure 6: Asian map depicting locations used for validating CLIMEX model for the number of generations of *Spodoptera litura* for the base year

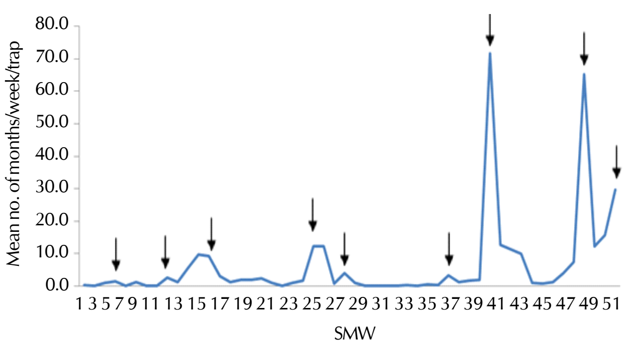


Figure 7: Mean pheromone trap catch of *S. litura* male moths/week/ trap in Bengaluru in 2012

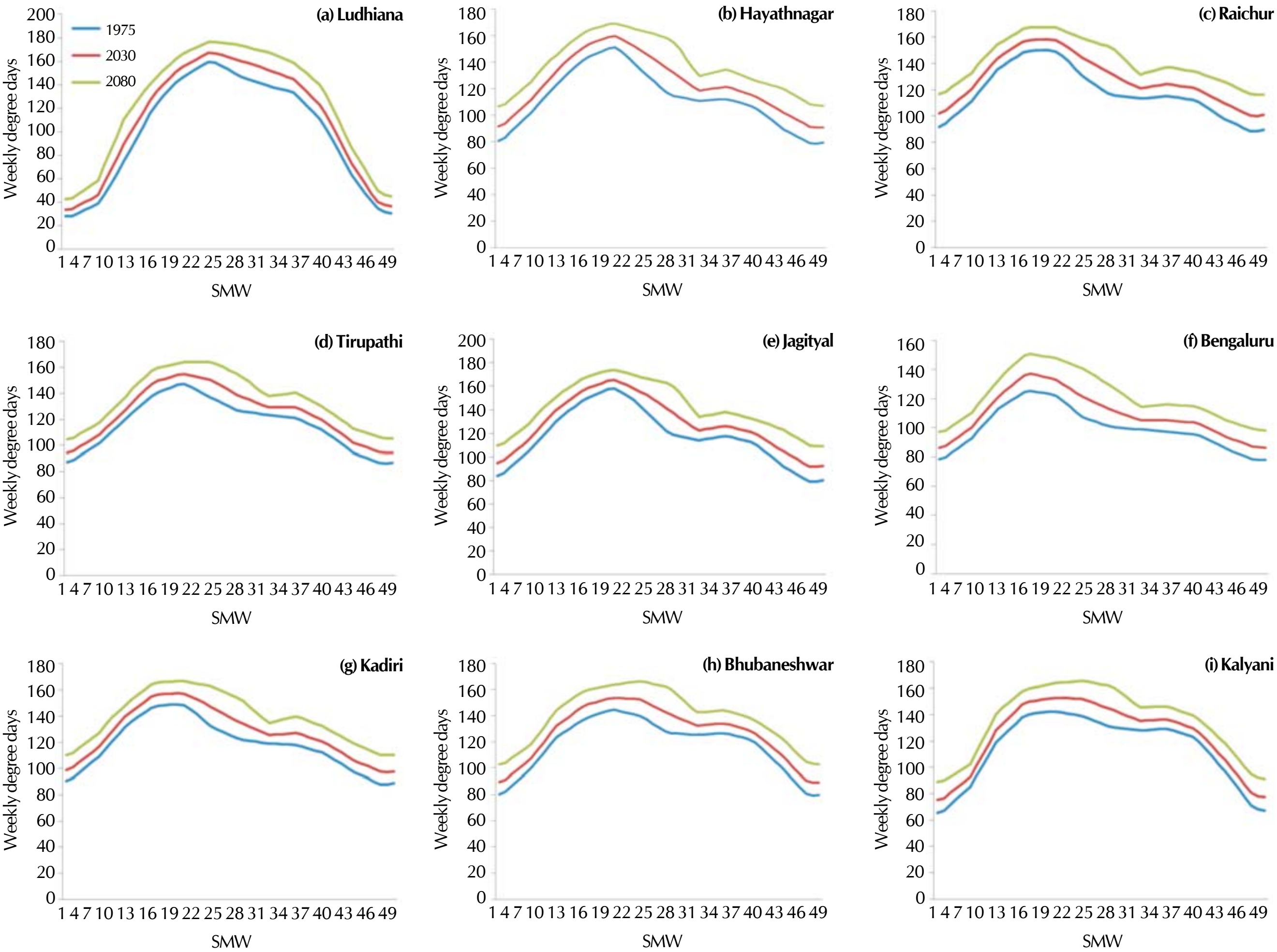
need to be increased as chance of determining pest outbreak happens in those regions with the faster development of the pest (Cividanes, 2000).

CLIMEX projects an increment of one or two generations by 2080 as compared to 7-10 generations available for baseline from literature (Rao *et al.,* 1991; Sridhar *et al.,* 2014). Also an increase of one to two generations is predicted for Bengaluru, Kalyani and Ludhiana in confirmation with the earlier analysis undertaken by the authors using Online UCIPM software (Sridhar *et al.,* 2014). The findings are also in agreement with Rao *et al.* (2014) for peanut growing locations *viz.*, Jalgaon, Raichur, Kadiri, Bhubaneshwar, Tirupathi, Hayathnagar and Jagityal. These similarities are due to the fact that all the three softwares (Online UCIPM, INGEN and CLIMEX) run analyses were based on Thermal Degree Days, horizontal cut-off method, predicting similar increase in number of generations by 2080 (Fig 9). Increase in the number of generations of the pest in India as predicted by CLIMEX covering all the agro-climatic zones, different host crops (as *S. litura* is polyphytophagous) and colour grades indicated regional variations based on the prevailing and predicted temperatures.

Thermal Degree Days are used in pest management initiatives world over (Johnson and Mayes, 1984; Fettig *et al.,* 2004; Arbab and Mcneill, 2011). However, such approach is not initiated in India except a few cases (Sridhar *et al.,* 2012a & b). Even in locations where TDD aided pest initiatives are practiced, lack of validation is one of the key reasons for lesser usage of degree-day models. This has been overcome in the present analysis by validating the results with ground data. The basis for the comparisons made between three software applications is the degree days based on horizontal cut-off method. Ultimately, development of such approaches and their successful transfer from lab to land would benefit not only in pest management, also helps to minimize insecticide resistance and preserve natural biocontrol organisms. However, as degree day models are mostly temperature-driven, the impact of other abiotic factors due to gradual increase in concentrations of CO_2, methane and nitrous oxide in the atmosphere (Siegenthaler *et al.,*2005; Spahni *et al.,* 2005; IPCC, 2007) also needs to be incorporated in understanding their combined effects on population development of pests. Similar prediction mapping of expected number of generations of Coffee leaf miner in Brazil is reported (Ghini *et al.,*2008).

Model validation

Validation of the model was done matching the number of generations of the pest in base year with available literature



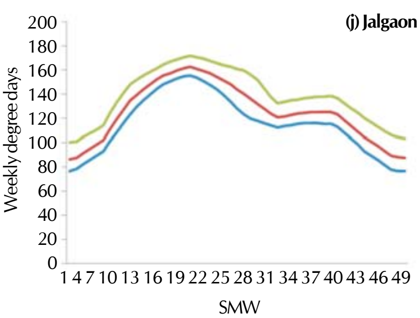


Figure 8: Weekly degree days for the selected ten locations (a-j) in India for the base year (1975), 2030 and 2080

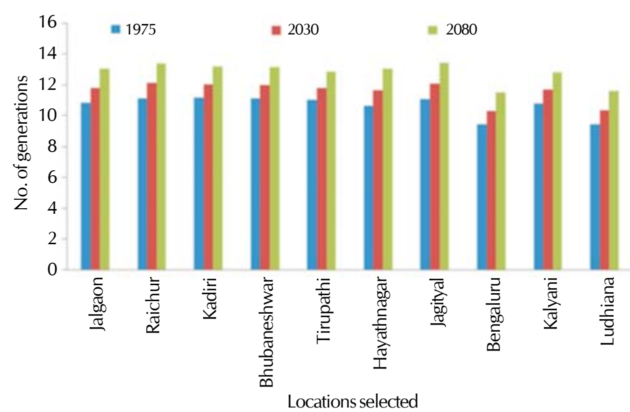


Figure 9: Number of generations/year in different locations of India for different time frames

and was in agreement with different locations considered. The observations match with the records of Nakasuji (1976) reporting four generations between May and October in Japan. Similarly our predictions are in agreement with the findings of Armes *et al*. (1997) with 8-11 generations/year for Asian countries; 8 to 10 generations/year in Papua New Guinea (Bruce, 2006); 3-6 generations/ year in Yunnan, China (Yan *et al.,* 2000); 4 generations in north China and 9 generations in south China (Guangdong); 4- 4.5 generations/ year in Hunan, China (Zeng *et al.,* 2010) (Fig. 6). Under Indian conditions observations from Pantnagar (Uttar Pradesh) with 7 generations (Rao *et al.,* 1991) and 12 generations from Andhra Pradesh (CABI, 2015) are also in agreement with our prediction. Also, the generation numbers were in close proximity with the observations of peak trap catches of *S. litura* in Bengaluru during 2012 (Sridhar *et al.,* 2014) (Fig.7).

The present findings are at par with the number of generations per annum obtained using other softwares like online UCIPM (Sridhar *et al.,* 2013a & b) and INGEN (Rao *et al.,* 2014) for the pest. CLIMEX based predictions for the ten locations spread across different agro-climatic zones showed a steady increase in the degree days (Fig. 8) and consequently an increment of one to two additional generations (Fig. 9) by 2080.

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