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Future scenarios of rice brown plant hopper *Nilaparvata lugens* (Stal.) under changing climate

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ABSTRACT

Abundance of brown plant hopper (BPH) *Nilaparvatalugens* (Stål) (Delphacidae: Homoptera) is modulated by prevalent weather conditions of rice growing seasons and locations. Categorization of BPH adults caught in light traps (nos/week/trap) into low, moderate and high and formulation of criteria accounting weather variables [maximum/ minimum/ mean temperature (ÚC), morning/evening/mean relative humidity (%), rainfall (mm) and sunshine hours (h/day) and wind speed (km/h)] during *kharif* of 2011-16 for four locations *viz.,* Ludhiana (Punjab), Chinsurah (West Bengal), Raipur (Chhattisgarh) and Aduthurai (Tamil Nadu) with associated rules for weather based BPH prediction. Validation of BPH predictions for *kharif* 2017 indicated 96, 87, 73 and 61% accuracies in respect of Aduthurai (TN), Raipur (CG), Ludhiana (PB) and Chinsurah (WB). Future weather based predictions of BPH based on climatic projections of representative concentration pathway (RCP) 4.5 for 2020, 2050 and 2080 indicated absence of high population at Chinsurah (WB) during all time periods of 2020-2080. Progressively reducing BPH abundance from past (2011) to all future periods was noticed at Aduthurai (TN). 'High' BPH from 2020 and beyond over 2011 and 2016 at Raipur (CG) and reducing 'high' but increasing 'moderate' category between 2020-2050 but the reverse in 2080 at Ludhiana (PB) were predicted indicating requirement of continued monitoring strategies put in place at these locations. The observed spatial variability of climate change influence on BPH implied a need for zonation mapping of rice insects including BPH for India.

Keywords : Brown plant hopper, weather, prediction, climatic projection, RCP 4.5

Twentieth century documented an increasing trend of surface temperature with no significant trends for rainfall across India (Rupa Kumar *et al*., 2006). Elevated levels of carbon dioxide, increased temperature and shifts in precipitation are the major processes of climate change that affect crop production. Effect of temperature has been described as an overwhelming factor on insects (Bale *et al.,*2002) with an estimated 2°C temperature leading to a maximum of five additional generations in life cycle of a given season (Yamamura and Kiritani, 1998). While assessment of direct effects of climate change on plants and insect herbivores under controlled experimental conditions have received research attention in the recent years (Sharma *et al.,* 2010; Rao *et al.,* 2016 and 2020) in India, the nature and magnitude on climate change impacting insects at field level in terms of change in species abundance and seasonal dynamics have only been projected based on phenological models for a few insects on some crops (Vennila *et al.,* 2019a; Rao *et al.,* 2020). Weather based models using heuristic and empirical approaches for different agroeco regions based on datasets of light traps have been found useful to predictthe severity of rice insect pests (Vennila *et al.,* 2016) that providesadvance information on timing and abundance of their population for use in pest management (Anon.2016). The use of such developed weather based models in conjunction with the future projections of climate change by IPCC provides an opportunity to understand the future scenarios of insect pests (Vennila *et al.,* 2019).

India grows rice in diverse ecosystems in 43.19 million hectares with a production and productivity of 110.15

million tons and 2550 kg/ha, respectively (Anonymous, 2018) and 84% of the national rice acreage during *kharif* contributes to 90 million tons of grains. West Bengal, Punjab, Chhattisgarh and Tamil Nadu cultivate rice in 5.15, 2.76, 3.83 and 1.44 million hectares with productivity levels of 2933, 3998, 2101and 2796 kg/ha and production shares of 13.7, 10.0, 7.31 and 3.67, per cent respectively (Anonymous, 2018). A yield loss of 25% to rice by insect pests (Dhaliwal *et al.*, 2010) necessitates 28% insecticide use on the crop. Brown plant hopper (BPH), [*Nilaparvatalugens*(Stal); Lepidoptera: Delphacidae] constitutes amonophagous and regular insect pest of rice in rainfed as well as irrigated wet land environments with its sporadic out breaks. Nymphs and adults are phloem feeders and de-sap plants by congregating at base above water level causing drying of tillers and hills resulting in scorched appearance in fields often referred as "hopper burn" (Backus *et al.,* 2005). BPH migration, brood emergence and their peaks are always monitored using light trapsand the daily catches recorded form the basis for understanding their spatial and temporal seasonal dynamics in rice ecosystems.Since, the weather factors determine the degree of development of BPH, establishing weather based predictions using the recent historical data sets with their validation is a powerful tool for decisions on time of its management. Current study is an investigationtowards prediction of BPH for future periods using the developed weather based approach and the climatic projections under representation concentration pathway (RCP) 4.5 of IPCC for different rice growing regions of India so as to strategize management of BPH during different periods of the current century.

MATERIALS AND METHODS

Four rice growing sites from four states belonging to different agro ecological regions under differing agro climate zones that were part of a larger programme of studies on impact of climate change under National Innovations in Climate Resilient Agriculture (NICRA) formed the target study locations (Table 1). Datasets on year round daily catches of BPH in light traps (Chinsurah type) were obtained from each of the locations for the periods of 2011-2017 for use towards development and validation of location specific weather based predictions. The data assembled were processed to obtain number of BPH numbers/trap/standard meteorological week (SMW). Weather observations *viz.,* maximum [Tmax], minimum [Tmin] and mean [Tmean] temperature (R°C), morning [RHI], evening [RHII] and mean (RHmean) relative humidity (%), rainfall [RF] (mm/week) and sunshine hours (h day^{-1}) [SSH] recorded from each of the locations on SMW basis were collected from respective meteorological observatories. Data of BPH catches in light trap (nos /trap/week) and weather variables pertaining to *kharif* (22-44 SMW) were used for development of rule based location specific predictions using heuristic approach.

Weather based predictions of BPH were attempted following an iterative and exploratory procedure involving three steps. As a first step, categorisation of BPH population levels into low, moderate and high was made considering the variability in BPH abundance over the *kharif* (22-44 SMW) duration of the six seasons (2011-2016) in respect of each location. The graphical constructions of mean, maximum and minimum abundance of BPH for each of SMWs across seasons in respect of each study location for the period of *kharif* (22-44 SMWs) served as the basis for categorizations (Vennila *et al.,* 2016). Secondly, congenial conditions of weather for BPH development reported in literature (Krishnaiah, 2014; Rath *et al.,* 2020) and their multiplication rate at 31+ 2! and the variability of the observed weather factors of 22-44 SMWs of 2011-16 were accounted to formulate suitable weather based criteria for each location. Thirdly, rules of prediction were developed combining the developed weather based criteria (step 2) and category of BPH population levels (step 1) towards prediction. Satisfying more than three, three and less than three weather criteria predicted high, moderate and low levels of BPH severity. Weather criteria were fine-tuned and finalised using the fixed prediction rules (step 3) while adjusting the pest severity categories (step 1) in such a way that more number of weeks (22-44 SMWs) of each season and across years (2011-16) predicted correctly the moderate and high pest severity in respect of the locations. Formulated weather based criteria were validated along with rules to predict the expected category of BPH abundance for *kharif* 2017 following. The actual weather observations of each study location from the respective meteorological observatory were obtained and assembled on SMW basis (22-44 SMWs) (step 1). Matching of the values of weather based criteria formulated with the observed values in respect of weather variables for each of SMWs was done (step 2). The rule of prediction was applied to get the 'predicted' category of BPH population abundance (step 3). The BPH abundance obtained through light traps in respect of SMWs of 22-44 of 2017 *kharif* was categorised using the pest severity scale (step 4) finalised for each location to get the 'observed' category.The category of BPH abundance predicted based

Table 1: Details of study locations for prediction of BPH under changing climate

Location	GPS Co-ordinates	Agro Climate Zone	Agro Ecological Region
Ludhiana – Punjab (PB)	30°54'N; 75°48'E	Trans-Gangetic Plains	Northern plain and central highland + Aravalis, hot semi-arid eco-region
Chinsurah - West Bengal (WB)	22°91'N, 82°E	Lower Gangetic Plains	Bengal and Assam plain hot sub humid to humid to per humid eco-region
Raipur – Chhattisgarh (CG)	21°30'N, 82°0'E	Eastern Plateau and Hills	Eastern plateau hot semi-humid eco-region
Aduthurai - Tamil Nadu (TN)	11°N, 79°3'E	East Coast Plains and Hills	Eastern coastal plain, hot sub-humid to semi-arid eco-region

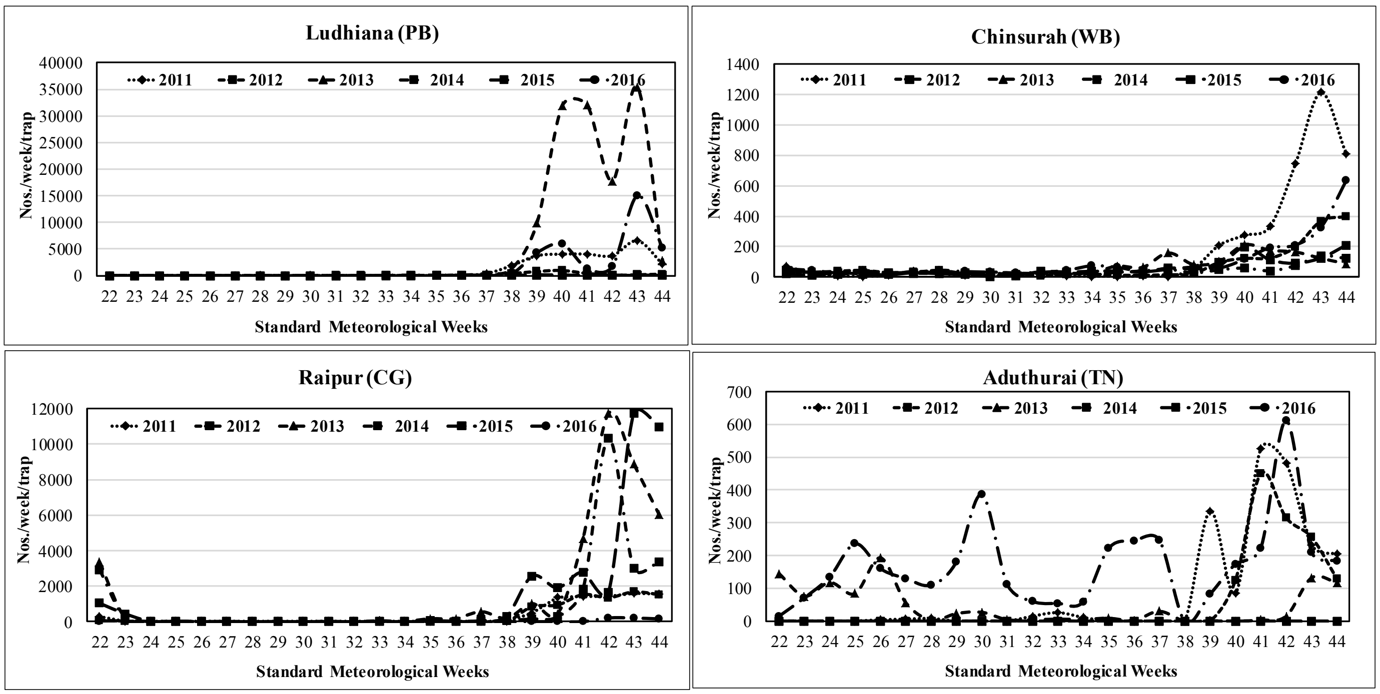

Fig.1: Seasonal dynamics of BPH during *kharif* 2011-2016

on weather based criteria using weather values and observed based on actual BPH catches were compared for each SMW for each study location (step 5). Number of weeks having both 'predicted' and 'observed' category of BPH abundance same or similar was counted out of the total number (23) of weeks under *kharif*. Prediction accuracy was calculated as the ratio of the number of weeks with correct predictions similar to the observed ones to the total number of weeks (23) and expressed in percent by multiplying with 100.

BPH abundance was predicted for future periods of 2020, 2050 and 2080 based on climatic projections for temperature (Tmax, Tmin & Tmean) and rainfall (RF) obtained through hybrid delta ensemble method (Islam *et al.,* 2014) for each of study locations for representative concentration pathway (RCP 4.5) (radioactive forcing at 4.5 W m^{-2} at stabilization after 2100) prescribed in fifth assessment report of inter-governmental panel for climate change (IPCC). Projected variables of weather (Tmax, Tmin, T mean & RF) for future periods along with other weather factors of latest of study season (2016) were used to predict the BPH abundance scenarios in respect of locationsbased on the weather criteria and prediction rule for 2020, 2050 and 2080 for comparison with observed abundance categories relating to *kharif* 2011, 2016 and 2017. The number of weeks under each category of BPH abundance in respect of different periods (past and future) was worked following the steps of prediction and compared through graphical formats.

RESULTS AND DISCUSSION

Study on seasonal dynamics of insects through regular monitoring using a standard sampling tool over multi seasons offer scope to understand their relative importance, inter-seasonal variability, periods of peak and multispecies

Table 2: Categorization of abundance, formulated weather criteria and rule of prediction for BPH

Location	BPH abundance (No. of BPH adults/trap/week)	Weather criteria*
Ludhiana (PB)	High (> 1000); Moderate (200-1000); Low (<200)	Tmean (26-28), RH mean (66-75), RF(<25), SSH (8-10), WS (0-5)
Chinsurah (WB)	High (> 200) Moderate (100-200) Low (<100)	Tmax (33-34), Tmin (22-25) RF(0-10), RHI (89-92), RHII (55-65),SSH (6-9)
Raipur (CG)	High (> 1000) Moderate (200-1000) Low (<200)	Tmean (22-28), RH mean (60-80), RF(<25), SSH (8-9), WS (0-5)
Aduthurai (TN)	High (> 500) Moderate (100-500) Low (<100)	Tmean (24-48), RH mean (>78%), RF(<25), SSH (8-9), WS (0-6)

*Rule of prediction: Satisfying more than three, three and less than three weather criteria predict high, moderate and low levels of BPH abundance

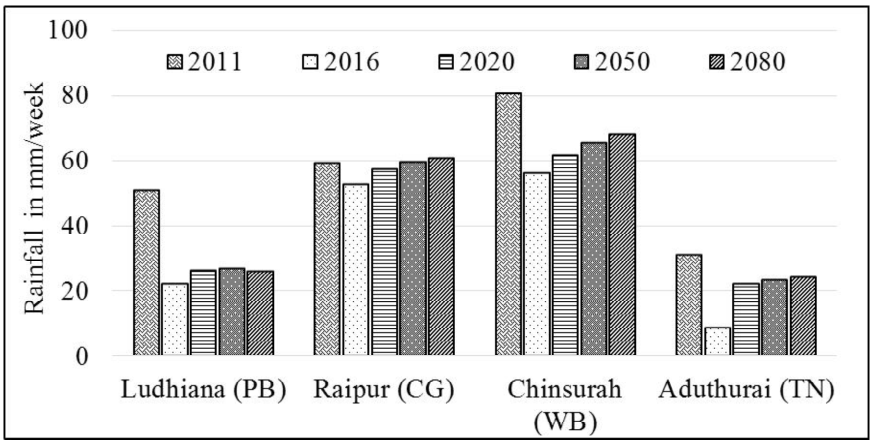

Fig.2: Validation of weather based predictions of BPH for *kharif* 2017

associations. Considering weather variables along with occurrenceof insects lead to establishing pest-weather relations that could be used in prediction of insects that facilitates management preparedness when needed.

Categorisation of BPH abundance

BPH seasonal dynamics (Fig. 1) *vis a vis* weather factors during *kharif* of 2011-16 (six seasons) from four rice growing locations were used to categorise population levels into high, moderate and low accounting the range of values during different SMWs in respect of each location. Varied scales for categorization were adopted considering the fact that the relative importance of BPH varied across locations of different agro climatic zones (as can be visualized by the 'x' axis scales of graphs in Fig.1) in addition to the spatial contiguity of rice fields determining area of operability of the light trap. Peak of BPH abundance was high at Ludhiana (PB) (>30000 nos/trap/week) during 2013. Raipur had the highest BPH peak during 2013 and 2015 (12000 nos/trap/ week). During 2014, BPH peak abundance was the highest (>10000 nos/trap/week) only at Raipur (CG). *Kharif* season of 2015 noticed least abundance of BPH at Ludhiana (PB) and Aduthurai (TN). While the most common period of occurrence of BPH was from 38 SMW in all four locations occasional early occurrences were obvious at Raipur (CG) (2013-2015) and Aduthurai (TN) (2013 & 2016). Aduthurai (TN) had a multimodal dynamics of BPH during 2016 completely different from other seasons. Mean population levels aggregated over six seasons were of the order (mean ±SD): 1423 ±5304>798±2164 >92±156 >59±114 (nos/ week/trap) in respect of Ludhiana(PB)>Raipur (CG) >Chinsurah (WB)>Aduthurai (TN).

Formulation of weather based criteria and prediction rule

Weather variables of temperature and relative humidity with their range of values constituting criteria in respect of locations are given in Table 2 along with a common rule of prediction. The inter seasonal variability of each of weather variables *viz.,* temperature (Tmax, Tmin and Tmean in R°C), relative humidity (morning (RHI),evening

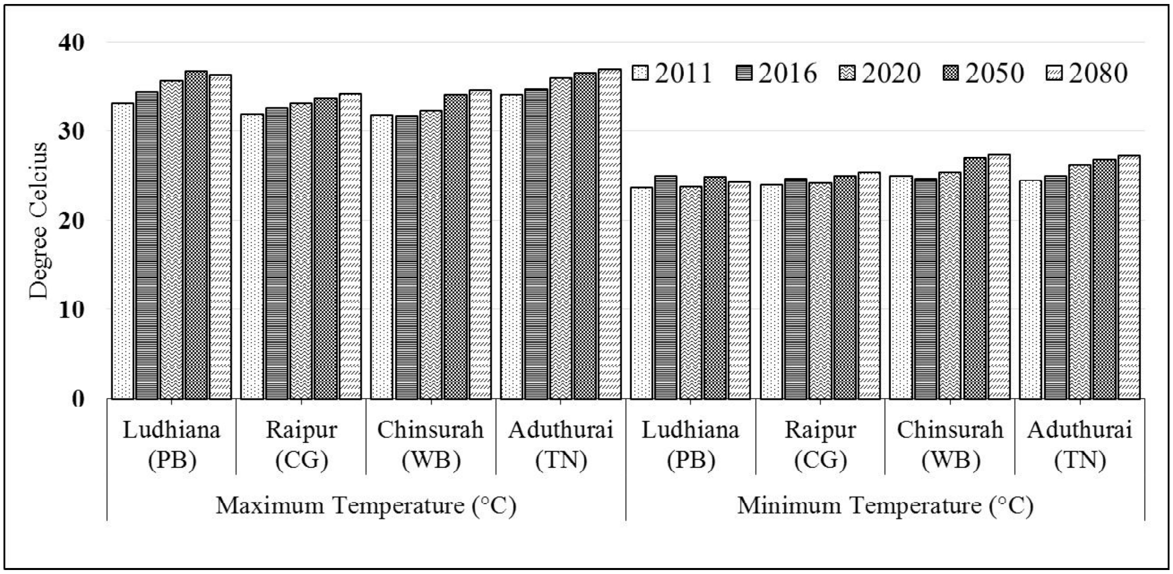

Fig.3: Maximum and minimum temperature of observed past (2011&2016) and RCP 4.5 future climate change periods (2020,2050 &2080)

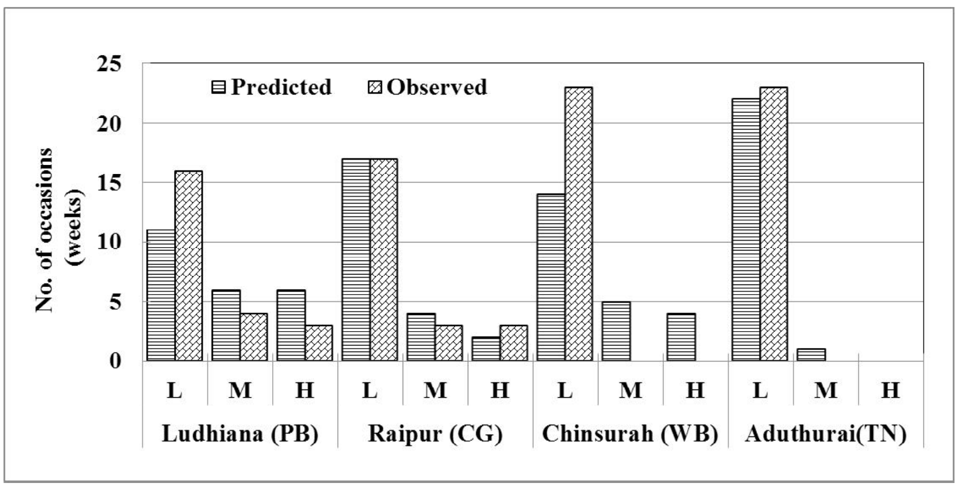

Fig.4: Rainfall of observed past (2011&2016) and RCP 4.5 future (2020,2050 &2080) periods

[RHII] and mean (RHmean) in %, rainfall (RF) in mm/week and sunshine hours (SSH in h day^{-1}) existed amongst seasons of 2011-16 were accounted while formulating the criteria. The differing criteria for different study locations of varied agroclimatic zones only point to the differential agro-climatic response of BPH in combination with ecological factors of microclimate of rice cropping systems. Ability of BPH to feed continuously with host plant availability up to 45°C with the lowest threshold and optimum temperature of 10°C and 22-27°C, respectively (Krishnaiah, 2014) and their multiplication rate at 31+ 2°C (Rath *et al.,* 2020) justify the differing criteria of prediction and abundance of BPH amongst study locations. The intra season variability during *kharif* for weather variables of temperature, relative humidity and rainfall are also larger amongst locations that their varied impact on BPH abundance through influence on rate of development stages of the insect and their dispersal is quiet a possibility in addition to the profile of cultivars grown in the vicinity of study locations. Since the weather factors are often interdependent, the present study accounted all possible variables while formulating criteria for use in BPH prediction in addition to the possibility that more the variables, the framing of rules became easier to define the abundance levels of high, moderate and low during the iterative analysis. More than three of the formulated criteria getting fulfilled for the identified variables predicted 'high' abundance of BPH. Prasannakumar and Chander (2014) had shown at Mandya (Karnataka) that peaks of BPH in

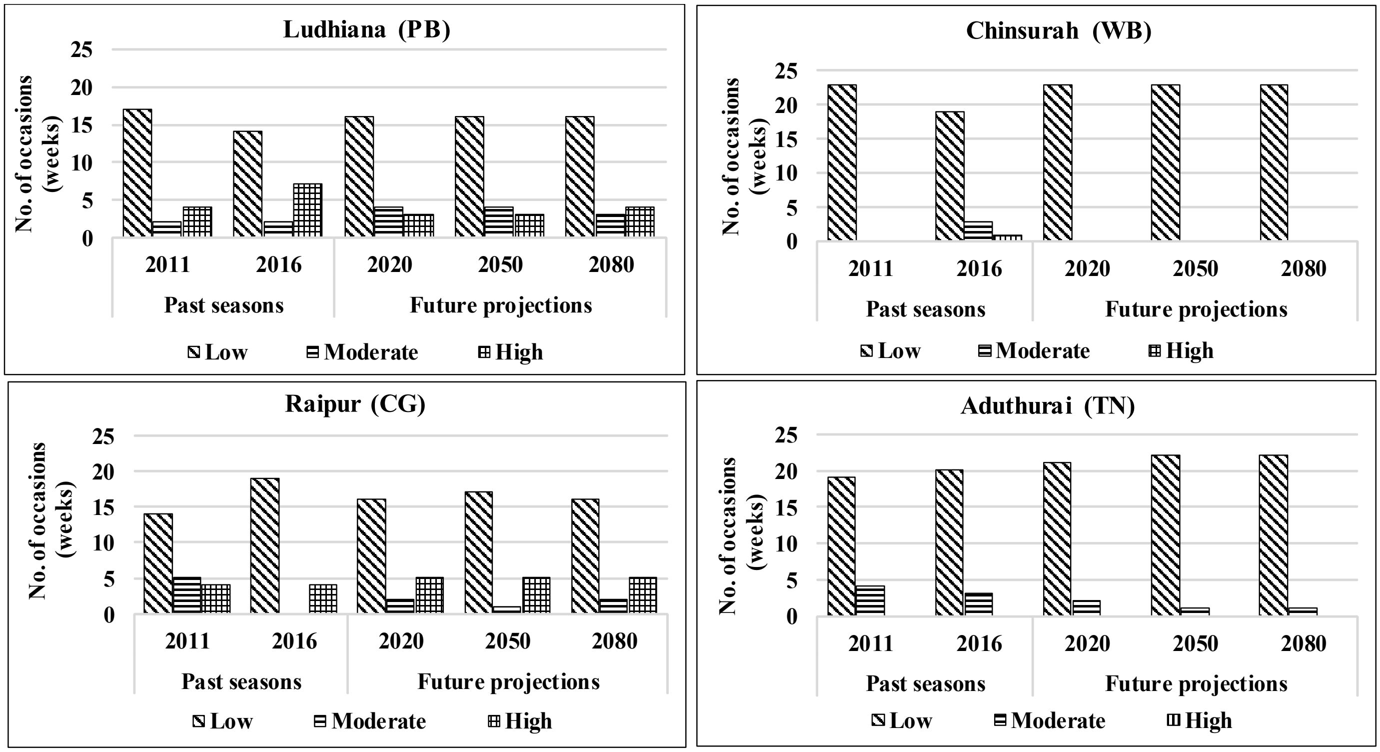

Fig. 5: Future projections of BPH for future periodsunder climate change (RCP 4.5)

light traps were significantly related to Tmax, RF and RHII based on stepwise regression analysis. Changes in ecological factors of micro-ecosystem of rice cultivation and the monsoon related winds having a role in BPH migration are attributed to the menace of BPH (Krishnaiah, 2014). Nevertheless, the conducive weather in combination with factors of crop production including the intensity of rice cultivation and resurgence of the insect to applied insecticides determine BPH abundance. Extensive use of insecticides for BPH management resulting in development of insecticide resistance and pyrethroids causing higher resurgence through enhancement of fecundity have been reported (Anand Kumar *et al.,* 2019). Differing seasons of BPH severity across states and seasons during last decade of current century indicated that the states of Haryana, Maharashtra, Odisha, Puducherry, Punjab, Tamil Nadu, Bihar and Andhra Pradesh had higher severity of BPH during 2010 although insect is distributed in most rice growing regions of India (Prakash, 2012).

Validation of BPH weather based predictions

Validation of the weather based predictions based on periods of 22-44 SMWs of *kharif* 2017 indicated 73, 87, 61and 96 % accuracies in respect of Ludhiana (PB), Raipur (CG), Chinsurah (WB) and Aduthurai (TN) (Fig 2). More than 70% prediction accuracies of BPH abundance amongst three of the four study locations suggested the role of atmospheric weather variables that could impact directly or indirectly or both ways. The lower prediction accuracy obtained for Chinsurah (WB) due to deviations of predicted BPH abundance as moderate or highfrom the observed low abundance noticed throughout the season could have been due to higher intra season variability for temperature, humidity and rainfall. Low prediction accuracies for yellow stem borer were also noticed at Chinsurah (WB) over 2011-16 *kharif* (Vennila *et al.,* 2016) pointing to the need for refinement either the weather based criteria or BPH abundance category in addition to careful examination of change of weather factors along the season.

BPH predictions under RCP 4.5 climate change projections

Many models and their versions projecting climate change scenarios are available and current study opted for RCP 4.5 level as it was near to situations of Indian scenario in terms of radioactive and green house emission variables (Chaturvedi *et al.,* 2012; Ramaraj *et al.,* 2014; Yaduvanshi *et al.,* 2019). Since India fits into the stabilization scenario of RCP 4.5 where in a range of technologies and strategies for reducing greenhouse gas emissions would be implemented in the future years, present study opted to use the climatic projections of RCP 4.5.

The climatic projections for the four rice growing study locations made at RCP 4.5 level (Fig. 3 & 4) for future periods of current century *viz.,* 2020, 2050 and 2080 indicated increasing maximum and minimum temperatures by about 1.7 to 0.8 R°C (hence mean also) across locations along future periods and against the observed past (2011 & 2016), although the trend of rainfall projections varied depending on location and over the past periods (Fig.5). It is interesting to note that the observed mean rainfall (mm/week) between 2011 and 2016 was glaringly different almost in all locations with Aduthurai (TN) showing highly reduced rains during 2016.All locations had increasing trend of maximum and minimum temperature along future periods up to 2080 with the exception of Ludhiana (PB) wherein minimum temperature projections had shown a decline by 1.2, 0.1 and 0.7 R°C in respect of 2020, 2050 and 2080. For all the locations, RF projections for 2020, 2050 and 2080 were higher over 2016 but lower over 2011 indicating the observed RF variability within the same decade.

Impact of climate change in rice cultivation reducing 6-10% yield by 2030 (Van Ittersum *et al.,* 2016) with situations (greenhouse gases+pollutants) projected to worsen in future years (Parker *et al.,* 2019) the response of poikilothermic insects to regional and long term uncertainties of climate are expected to be varied. Future predictions of BPH for future scenarios of climate change indicated increasing 'moderate' and declining 'high' abundance during all future years over the past periods (2011 & 2016) at Ludhiana (PB). While the observed severity at Raipur (CG) showed similar 'high' between 2011 and 2016, the later period had more occasions of 'low' abundance over 2011. Future predictions showed similar levels of 'high' abundance of BPH with slight reduction in 'moderate' during 2050 over 2020 and 2080. Chinsurah (WB) had exclusively 'low' abundance of BPH amongst 2011 (past) and future (2020, 2050 & 2080) periods with 2016 and 2017 (validation year) showing all three (low, moderate and high) categories of BPH abundance. However, at Aduthurai (TN), decline and increase in respect of 'moderate' and 'low' abundance was noted beyond 2011, implying the decreased levels of BPH during current and future years of current century. Ludhiana (PB) and Raipur (CG) are the locations that would have periods of moderate to high abundance of BPH in the coming years thus emphasising the need for continued monitoring for BPH dynamics during *kharif* that vary along a given crop season amongst locations.

CONCLUSION

As insect development depends both on magnitude and distribution of weather variables, the weather-based prediction of BPH based on iterative and exploratory analysis of data sets over many seasons was found to be an effective tool toknow the forthcoming insect abundance. Varying BPH population levels amongst differing rice eco regions of the study necessitated formulation of location specific scale for categories of 'low', 'moderate' and 'high' BPH abundance as well asweather based criteria with associated rules resulting in 61-96% prediction accuracies. Future abundance based on RCP 4.5 climatic projections had predicted decreasing levels of BPH during the forthcoming *kharif* seasons of current century at Chinsurah (WB) and Aduthurai (TN). Moderate to high abundance forecast of BPH for future over the past and present periods implied the importance of climate change on BPH dynamics at Ludhiana (PB) and Raipur (CG) and the continued need for monitoring from pest management perspective.

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