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Mapping foliage damage index and monitoring of *Pieris brassicae* by using GIS-GPS technology on cole crops

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Abstract
Experiments were conducted from 2012-2014 to develop the georefrenced maps on cole crops for observing foliage damage index (FDI) and hot spots for cabbage butterfly in Ganderbal, Budgam, Anantnag, Srinagar, Kulgam, Baramulla and Pulwama districts of Kashmir Valley. Data revealed that, among the locations, Chadura (Budgam) recorded highest (3.60) and lowest from Wanpow (Anantnag) (1.80), FDI on Kale, respectively. Whereas, among the locations, during two survey periods, Zazun (Ganderbal) recorded the highest (100 and 90) and Arampora (Kulgam) recorded the lowest (10 & and 20) butterfly index, respectively, on geographic information system (GIS) Map. Among the aspects, north-western direction, and highest elevations recorded highest butterfly numbers.

Keywords: mapping, cole crops, climate change, cabbage butterfly, GIS-GPS

1. Introduction

An impact of climate change on insect populations and their pest status has gained high momentum worldwide. Most of the research conducted so far has been targeted on modelling insect populations [1-4], distribution [4-6], development [7, 8], migration [9], dispersal [10-12], and altitude [13]. Studies have revealed that insects are the best indicators of climate change [14-16], because of their poikilothermic nature. The effect of climatic systems and variables, crops grown in a particular habitat, agro-technology variability, even cropping methods influencing insect population/infestation has not been analysed properly. Further, there is no report on the development of a georeferenced map for monitoring/assessing the damage caused by the larvae of *Pieris brassicae* (L.) in cole crops. *P. brassicae* is cosmopolitan in distribution, is an important pest of vegetables and most prevalent in the temperate climatic regions of the world [17]. Cruciferous crops *viz*: -cabbage, cauliflower, kale and knol khol are grown mostly for seed purposes, because of the unique temperate climatic requirement for raising seeds [18]. Various insect pests feed on vegetables in different parts of India and in the Kashmir valley. It has been estimated that damage caused by insects alone reduces the yield of about 40 per cent annually in different vegetable [19]. Cole crops like cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*B. oleracea* var. botrytis), Chinese cabbage (*B. chinensis*), broccoli (*B. oleracea* var. *italica*), brussel sprouts (*B. oleracea* var. gemmifera) originated from the Mediterranean region [19, 20]. *P. brassicae* has a wide host range, infest about 83 species of the Cruciferae family and occurs in different climatic conditions in various states of India and the other countries as well. It damages seedling, vegetative and flowering stages of the plant [21]. Since the climatic conditions are not similar at all places, modelling the population in one climatic zone and predicting the same in other climatic zones is a challenging issue. This has many implications in predicting insect infestation and the management thereof.

Monitoring data from forest ecosystem, grassy lands, and different patches have not been used in agricultural environments for *P. brassicae* monitoring. Although Porter *et al.* [22] generated prediction models for some insects; monitoring of cabbage butterfly separately on all cole crops is complex, because the availability of commercial patches and non-commercial patches is not continuous in Kashmir valley. Farmers in such regions grow these crops either scientifically or in traditional ways, mostly by mixed and mono-cropping. Therefore, it was difficult to monitor the population separately on different cole crops and surveyors were unable to find the big patches, where the line transect method [23] for adult monitoring could be followed separately on all cole crops. Monitoring of butterflies is either done by Pollard walks [24]

Or Capture Mark Recapture (CMR).

Pieris brassicae is considered as an important pest in the agricultural ecosystem and the damage is high due to the conversion of vegetable belts into horticulture. Insect population monitoring is very important for pest managers, insect modellers, and climate change specialists [25-27]. Jammu and Kashmir has cool climate and huge mountains. To our knowledge, no work has been conducted for cabbage butterfly infestation and losses, especially on kale, knol khol, cabbage and cauliflower crops, which are of significant importance. As such the study was undertaken to see the impact of elevations from the intensive hot spots on the population of the cabbage butterfly. To address the issues; (i) mapping of foliage damage index by *P. brassicae* on cole crops from the sampling sites using global positioning system (GPS) and geographic information system (GIS) technologies and (ii) the impact of important climatic and geographical variables on monitoring and adopted method were carried out. The georeferenced maps could form an important tool for quantifying the damage on cole crops through satellite images for forecasting cabbage butterfly damage.

2. Materials and Methods

2.1 Study Area

The state of Jammu and Kashmir is situated in the north of India. Geographically, the state is divided into three regions, *viz*. Jammu, Kashmir and Ladakh. Kashmir is a Valley and lies between 33^0.20/ and 43^0.54/ N latitude and 73^0.55/ and 75^0.35/ E longitude covering an area of 15,948 Sq. Kms with 64% of the total area being mountainous [28]. The Valley is divided into ten administrative districts, out of which, seven districts were selected for the survey of cabbage butterfly damage on cole crops, which included Ganderbal, Budgam, Anantnag, Srinagar, Kulgam, Baramulla and Pulwama. Bandipora, Shopian and Kupwara districts are commercial fruit belts and were excluded from the study. The monitoring and damage assessments were carried out in the respective districts especially from the sites that are known for the cultivation of vegetable crops.

2.2 Determine the foliage damage index on cole crops

A survey was conducted in Kashmir valley in different areas/localities at the peak infestation stage in all the administrative districts, depending on the prevailing weather conditions and the butterfly activity to identify the hotspots for cabbage butterfly during 2012-2014. Foliage damage index (FDI) was assessed by determining the ratio of leaves with holes caused by larval feeding to the total number of leaves on the plants and was calculated as per the method adopted by Tompkins *et al* [29].

The coordinates for the hotspots of *P. brassicae* during the survey programme were tracked by GPS (Make: Garmin; Model: Oregon 555) and the field data for FDI was recorded in shape files and were transferred to computers housed in Centre for Climate Change and Mountain Agriculture (CCCMA), SKUAST-Kashmir. ARC View GIS software (ver. 16) was used to create GIS Maps. Distribution and level of FDI were determined from all the locations of the Kashmir valley on cole crops as per the above rating scale to develop georeferenced maps for the damage assessment in the agricultural ecosystem on cole crops by using GPS technology separately for kale, knol khol and cabbage.

2.3 Method adoption for *P. brassicae* monitoring in agriculture ecosystem

The survey was conducted by two ways: Pollard walk and CMR Techniques. The pollard walk was used for monitoring due to less population of adults seen in agriculture ecosystem. The *P. brassicae* adults were collected and marked as per CMR method. The captured butterflies were released in the same agroecosystem but the marked butterflies were not seen. Thus, Pollard walk way technique was followed to assess the butterfly populations throughout sample sites in the Kashmir valley.

2.4 Monitoring cabbage butterfly in Kashmir valley

The survey was conducted from all the hotspots for monitoring the adult population of cabbage butterfly by the line transect method [23, 30], during May to June and July to August, from all the selected locations. However, the monitoring of cabbage butterfly was continuously performed from the emergence to disappearance at the Shalimar site only during 2013. It was not possible to monitor its population separately on different cole crops, as the scarcity of continuous big plots for different cole crops, mixed cropping, grasses all around the boundaries of irrigation channels, some areas with trees on the boundaries, and also length of patch, and even uniform transect routes were needed separately on each crop for monitoring. Therefore, monitoring was done at all the experimental locations from permanent transect routes determined as hotspots for the cabbage butterfly irrespective of selective monitoring on the type of cole crops.

2.5 *Pieris brassicae* recording

Survey for the transect count of *P. brassicae* was done by moving at a constant speed for 60 minutes at each hotspot or sites selected for recording *P. brassicae* in a 100 meter permanent transect in an agricultural ecosystem and the count was recorded for a five-meter radius covering right/either side and front during good weather conditions, the butterfly index was calculated as suggested by Thomas [31].

2.6 Statistical Analysis

Data on FDI on kale, cabbage and knol khol, and the butterfly index of *P. brassicae* were subjected to line regression method to develop a relationship between FDI and butterfly index, from the selected sites. Further, from aspects, butterfly index was compared with different aspects. Different elevations from the intense hot spots of cabbage butterfly were analysed by regression equation with butterfly index. Weather data were taken from the mini-weather station of SKUAST -K located at the Shalimar site. Multivoltine cabbage butterfly populations were observed at the Shalimar site on cole crops in agricultural ecosystem. Continuous monitoring of *P. brassicae* was done from its emergence to the disappearance. The butterfly index of these generations were calculated and regressed with maximum temperature, sunshine hours, dates and appearance dates of cabbage butterfly. ARC GIS, software (ver.16) was used as a tool for developing GIS maps for FDI and monitoring of *P. brassicae* from the georeferenced sites and ANOVA was used for statistical analysis.

3. Results

3.1 Foliage damage index on cole crops

The survey sites for sampling cole crops from the hotspots to assess the damage by *P. brassicae* are shown in separate GIS maps for cabbage (Map 1), kale (Map 2) and knol khol (Map 3) for FDI. The FDI on kale, cabbage and knol khol was developed by using GPS/GIS technology to create maps to determine the infestation levels by *P. brassicae*. The relationship between FDI and butterfly index calculated by linear regression is shown in Table 1. Butterfly index and FDI from respective sites showed positive relationship with kale (F = 0.241, P = 0.634), cabbage (F = 0.770, P = 0.400) and knol khol (F = 0.121, P = 0.735).

Chadura location showed highest FDI of 3.60, 3.50 and 3.0 on kale, cabbage and knol khol, respectively, and the lowest FDI (1.80) on kale at Wanpow among the selected locations/sites. Among the districts, the highest FDI (3.06, 3.00 and 3.16) was observed in district Budgam followed by Srinagar (2.66, 2.33 and 2.80) on kale, cabbage and knol khol, respectively.

Among the total hotspots of cabbage butterfly, ten locations grow kale, cabbage and knol khol, while, only two locations (Wanpow and Wanigund) grow only kale. All these hotspots were determined on the basis of FDI caused by *P. brassicae*, which varied from location to location based on longitudinal and latitudinal gradients and elevations of the respective sites.

3.2 Monitoring of cabbage butterfly in Kashmir Valley

Among the selected sites, Zazun recorded the highest population count of *P. brassicae* followed by Chadura, whereas, Arampora and Wanigund recorded the lowest population count of cabbage butterfly during May to June. The population of the butterfly showed the same trend as depicted in the next visit during July to August. When comparing the elevations, the higher numbers of butterflies were observed at higher elevations (represented in feet) compared to the lower ones (Fig. 1) with strong regression equation (Y = 0.119x-595.7) and regression coefficient of R^2 = 0.808. Further, the North Western locations recorded the highest number of butterflies compared to the southern locations (Fig. 2). The butterfly population during two survey periods (May-June and July –August) at different locations is depicted on GIS Map (Map 4). Further, the butterfly index is more on lower longitudes compared to higher ones at the different locations (Fig. 3).

Monitoring of cabbage butterfly was done throughout the year (i.e., first appearance to disappearance) at the Shalimar site. The butterfly first emerged on 7th of April and disappeared on 20th of October. The time between butterfly emergences to disappearance was used to simulate the population dynamics of the adult *P. brassicae* at the Shalimar site. The simulation method was developed for the first emergence, peak and emergence of new generations for four and a half generations (Fig. 4) based on the observed and predicted population using pest monitoring data.

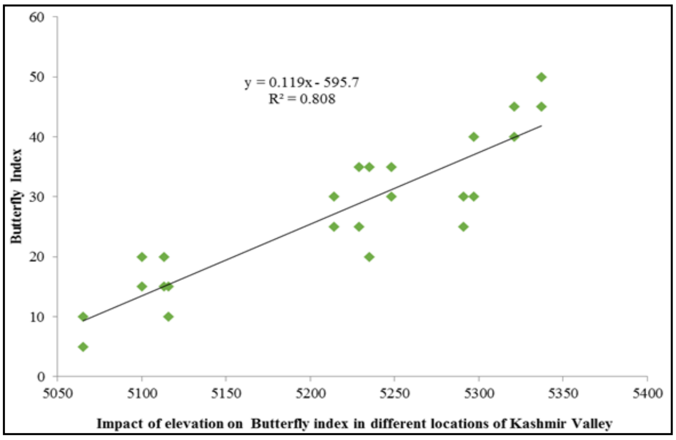


Fig 1: Regression trend line for depicting impact of elevation on butterfly index in different elevations of Kashmir Valley. (Elevation in feets)

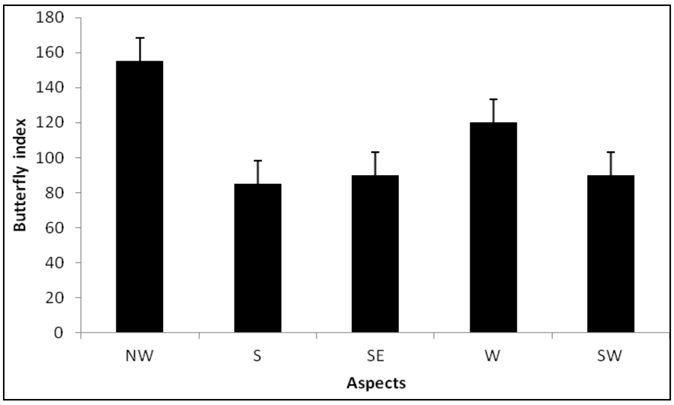


Fig 2: Impact of aspects on butterfly index of cabbage butterfly in different locations of Kashmir Valley. NW = Northwest, S = South, SE = Southeast, W = West and SW = Southwest

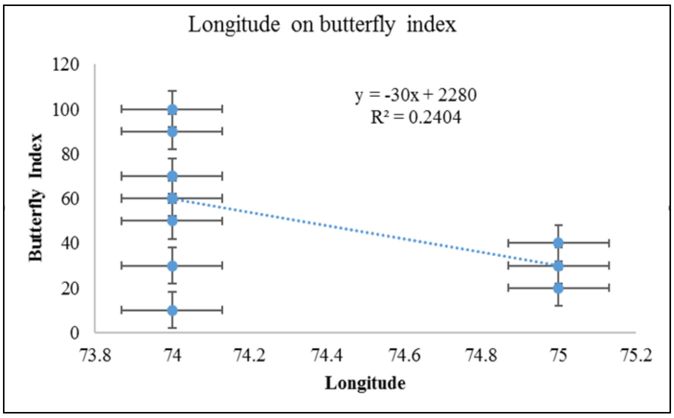
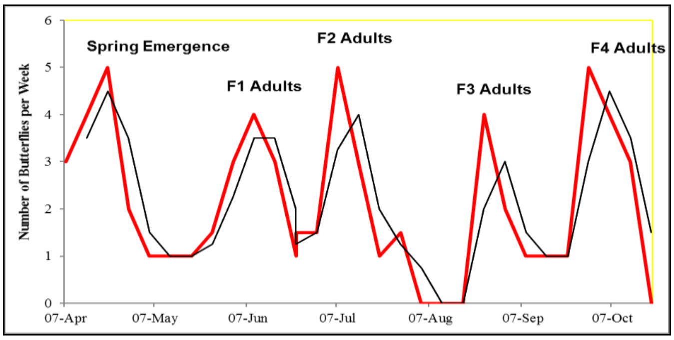


Fig 3: Impact of longitude on butterfly index in different hot spots of cabbage in Kashmir Valley



- Red line is predicted population of cabbage butterfly
- Black line is observed population of cabbage butterfly

Fig 4: Monitoring cabbage butterfly populations on weekly basis at Shalimar campus during 2013

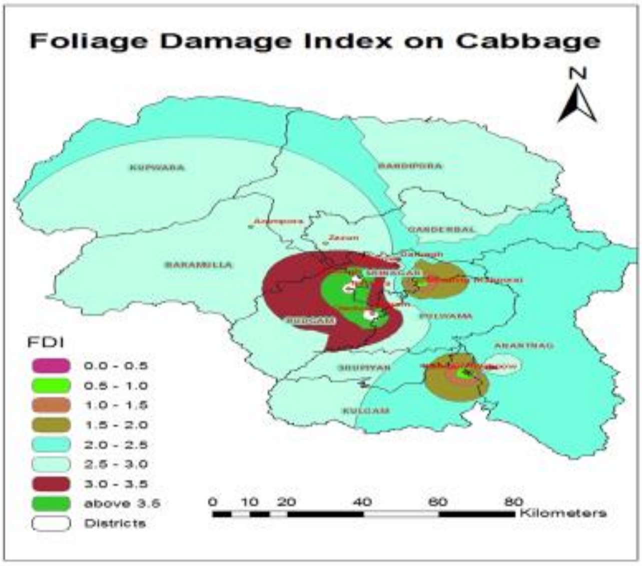
Table 1: Interaction between foliage damage index (FDI) and butterfly index (B I) in different locations of Kashmir valley

Parameters	Equation	Regression Coefficient	Significance*
BI X FDI (cabbage)	Y = 1.014x+60.758	0.0186	F = 0.770, P = 0.400
BI X FDI (Kale)	Y = 0.0035x+2.3768	0.027	F = 0.241, P = 0.634
BI X FDI (Knol Khol)	Y = 0.0132x+1.5341	0.1445	F = 0.121, P = 0.735

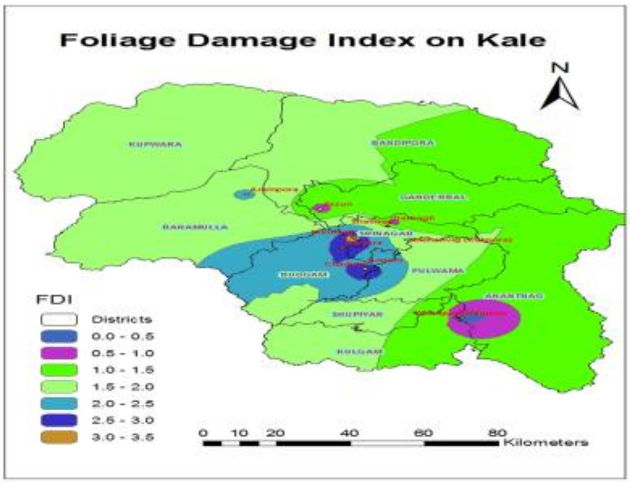
*Significant at 5% level of Significance.

Table 2: Trend line reliability of different weather variables with the different generations of the *Pieris brassicae* on cole crops at Shalimar Campus.

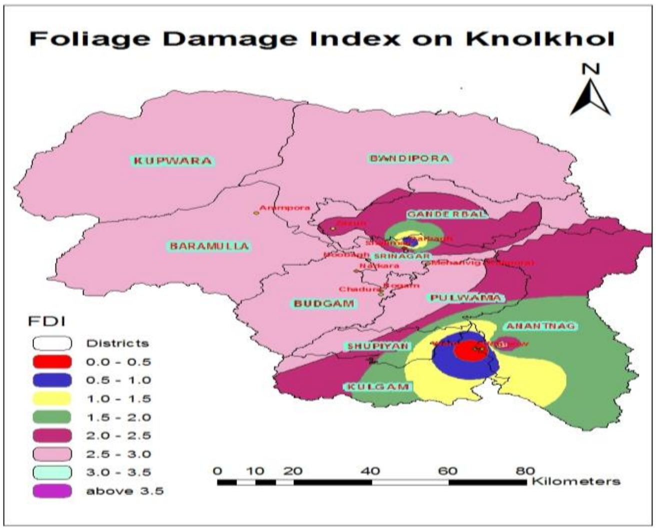
Parameters	Equation	R^2
B.I X Dates (1st Gen)	Y=-1.3571x+57261	0.7934
B.I X temperature	Y=-0.2385x+34.538	0.6444
B.I X Sunshine	Y=0.6087x -8.4767	0.6562
Temperature X sunshine	Y=0.06087x +8.4767	0.6500
B.I X Dates (2nd Gen)	Y=-1.7857x +75388	0.8065
B.I X temperature	Y=-0.0071x +30.561	0.0028
B.I X Sunshine	Y=0.0632x +6.0903	0.1114
Temperature X sunshine	Y=0.6237x +25.541	0.7644
B.I X Dates (3rd Gen)	Y=-1.4286x +6038	0.75
B.I X temperature	Y=-0.075x +27.300	0.0745
B.I X Sunshine	Y=0.2433x +11.047	0.4093
Temperature X sunshine	Y=0.4041x -26.303	0.3129
App. Dates X B.I (spring)	Y=-0.3929x +16575	0.2687
B.I X temperature	Y= -0.0248x +22.649	0.4297
B.I X Sunshine	Y=0.5827x +-5.8295	0.0067



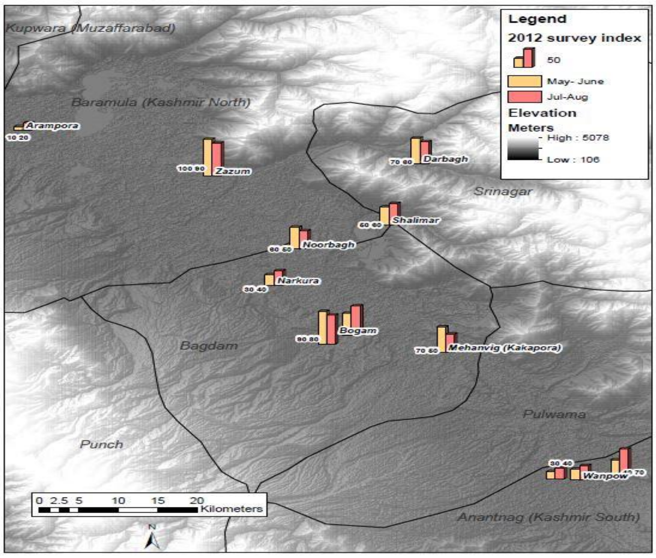
Map 1: Map showing damage assessment scale on the basis of foliage damage index (FDI) of *Pieris brassicae* in Kashmir Valley on Cabbage



Map 2: Map showing damage assessment scale on the basis of foliage damage index (FDI) of *Pieris brassicae* in Kashmir Valley on Kale



Map 3: Map showing damage assessment scale on the basis of foliage damage index (FDI) of *Pieris brassicae* in Kashmir Valley on Knol Khol



Map 4: GIS Map showing butterfly population during two survey periods (May-June and July –August) at different locations.

4. Discussion

The host specificity of cabbage butterfly for egg laying is very strong. The repeated disturbances of capturing and recapturing by CMR method, reported by Morton [32] have not been fully understood. The CMR technique may lead to physical frightening of cabbage butterfly from the captured areas. It is a tedious task to capture adult *P. brassicae* in the managed agriculture ecosystem due to the availability of very few nectar-producing plants. The aim of the butterfly is to continue its progeny on the preferred hosts. The other phenological stages of *P. brassicae* are sedentary and the selection of the crop for healthy progeny is governed by the adult females as the caterpillars feed on the same plant. Species-specific behaviours vary within insect species and ecologists advocate planting nectar-producing plants for the conservation of butterflies. This will also maintain the population of natural enemies of cabbage butterfly. The count and damage index of cabbage butterfly is a major concern in managed agriculture ecosystem, where growers spray insecticides for its management. Our monitoring programmes were not selective either on managed or unmanaged vegetable belts.

In managed agroecosystems, no data on the relationship between infestation and butterfly index is available [16]. Further, the reflections of the population sizes and trends by Pollard walks are still unclear [33]. Therefore, multiple sites were selected for the damage assessment as well as for monitoring *P. brassicae* in managed agricultural ecosystem. The linear regression analysis carried out with temperature, sunshine, monitoring and appearance dates of *P. brassicae* showed a negative relationship with temperature, appearance and monitoring dates in all the generations. However, sunshine hours showed a positively significant relationship. Further, regression analysis showed a positively strong relationship between temperature and sunshine (Table 2). Temperature is considered as an important variable for climate change and directly or indirectly affects the insect population dynamics and is the most important variable for the year to year population fluctuations, and infestation levels [7]. However, present study revealed a significant impact of elevations on butterfly populations. Thus, temperature alone is not the only factor for butterfly population but the thermal tolerance of insects, locations, ecosystems and snow melting impact the sedentary stages of cabbage butterfly. The population of *P. brassicae* was strongly related to geographical gradients, such as elevation, longitude and aspects. The strong effects of variability from the hotspots/sites were not available except for the Shalimar site that showed some climatic differences with the population emergence and disappearance of populations. Further, strong effects of elevation among the sites were observed. *P. brassicae* population was greater at high elevations and in north western direction, depicting more population in the cooler areas. This might be due to the lofty mountains and cool climate at higher elevations compared to rest of India. It could be difficult for the natural enemies to track them and adapt to new hosts. Jamdar [34] also reported the migration of *P. brassicae* towards north western Kashmir Valley but a concrete study was not conducted. Harrington *et al.* [26] stated that insects require certain heat units to complete their development, which varies from insect to insect. The GIS/GPS technology along with damage assessment from the monitoring sites of Kashmir valley on cole crops is a good approach for future use and the present study could be used to estimate the damage done by the pest on cole crops using the GPS technology. Therefore, GIS maps are well suited for monitoring and developing management strategy for the cabbage butterfly by developing the distribution map of this pest.

The temperature and sunshine are important variables that impact the butterfly population [7]. Temperature has a profound effect as photoperiod requirement for butterflies and the emergence of butterflies starts with the onset of spring. The temperature has a significant negative effect on the insects as the life cycle and diapause are programmed [7, 26], and insect phenology is mostly driven to mountains, undisturbed by the managed ecosystem and vice versa. These differences are attributed to the migration [27] and hosts suitability [17]. Most of the butterflies, including *Pieris rapae* fly during May and June (spring) and July and August (summer) [16]. Summer diapause and disappearance of adults during winter and migration approach towards northern direction is highly dynamic that makes monitoring challenging but targeting their breeding and damage sites using georeferenced maps as revealed from the present study, may lead to the new pathways for the insect modellers in agriculture ecosystem through satellite imagery for precise pest management programmes. We could not forecast the *P. brassicae* and other few related butterflies on cole crops as the previous data for damage and adult population for these sites were not available. In-depth studies are required to develop a model for *P. brassicae* based on the data generated in this study to forecast the pest invasion. This could form an important strategy towards the management of this pest in cole crops.

5. Conclusion
Monitoring adult *P. brassicae* population was performed for the first time on cole crops in India. The numbers of butterflies observed increased with the elevations. Further, the southern sides of the monitoring sites showed the lowest numbers of butterflies compared to the other sides. These georeferenced maps can be utilised to assess foliage damage in future by using satellite images and could play an important role in developing pest management strategies for cabbage butterfly.

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