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# Surrounding landscape influences the abundance of insect predators in rice field

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## Abstract

**Background:** Natural enemy abundance in a crop plot depends on its prey presence and also influenced by habitats close to field. Landscape changes are also important factors driving pest and natural enemy population abundance in a specific crop field. Examining these kinds of effects on insect pests or biocontrol agents, as well as analysis of their functional food webs, would be asset to make a fruitful pest management programme at local scales. Therefore, this study was undertaken to evaluate the impact of surrounding landscape on the abundance insect predators in rice field.

**Results:** This study revealed a dependency on rice bund margin width, with spider populations increasing with increased bund widths. Conversely, population abundance did not rely on the number of weed species observed on earthen ridge around the rice field. In general, relative abundances of predator populations differed significantly across the three landscapes tested. Among the four predators of rice insect pest, the green mirid bug showed highest number irrespective of landscape. Comparatively, higher predator diversity (Shanon diversity) was observed in landscape I followed by landscape III and landscape II. All landscapes showed different diversity indices indicating heterozygosity existed in each study site. These landscape diversity influences the predator's abundances at a local scale. Variogram derived from this study also indicated the landscape heterozygosity existed in studied locations which can also explain the predator's abundances in rice field at locale scale.

**Conclusion:** These findings suggest that predators of rice insect pests are landscape specific. Therefore, characterization of each local landscape in Bangladesh rice production landscapes are necessary before planning and implementation of integrated pest management. Geospatial analysis of local landscape would be more effective to analyze such unique characteristics. As a step in this direction, preliminary variography analyses using the RED spectral band of December 2016 LANDSAT 8 imagery propose an initial learning suite of methods for describing useful local characteristics affecting rice pest predators.

**Keywords:** Rice landscape, Natural enemies, Location, Population dynamics, Variography, LANDSAT 8

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## Background

Rice (*Oryza sativa* L.), the staple diet for more than half of global people, cultivate in 158 million hectares of land globally. In Bangladesh, rice occupies about 77% of the cropped areas [1], accounting for a total 11.6 million hectares that produced 34 million tons of milled rice [2]. There are three rice growing seasons in Bangladesh including *Aus* (monsoon rice), *Aman* (rain-fed with supplemental irrigation) consisting of two types of production (broadcasted Aman and transplanted Aman), and *Boro* (irrigated rice) [3]. Rice is cultivated throughout the year, and the intensity of cultivation is now increasing day by day to meet greater demands from more people living in Bangladesh every year. The rice agroecosystem covers the major part of the non-urban land area in Bangladesh. These rice eco-systems are inhabited by hundreds of arthropod species performing a variety of ecological functioning (such as predation, pollination and decomposition) [4].

To date, 267 rice insect pests and 375 beneficial arthropod species have been identified from the rice ecosystem in Bangladesh [5, 6]. Comparatively, however, while fewer than twenty species can cause significant yield losses in India, Bangladesh numbers from twenty to thirty-three total species considered important for economic damage to rice production [7]. These pest species, in turn, are subjected to attack, and are sometimes kept in check, by predators and parasitoids. This complex functional food web constantly drives toward an equilibrium that mitigates abnormal increases in the abundance of pest species in rice field. However, this equilibrium is also often broken due to the heavy use of synthetic fertilizers and pesticides [8]. This breakdown in the ecological resilience of a rice farm often induces pest outbreaks [9] that affect worldwide economic damage to rice growers.

Scientists have long noted how indiscriminate use of pesticide is a principle reason for major outbreaks of insect pests in many kinds of crop production plots [10]. A recent example in rice is the increase in outbreak frequency of brown planthopper (*Nilaparvata lugens*) across numerous Asian rice-growing countries from 2005 to 2012. Application of broad-spectrum insecticides for controlling other insect pests in rice enhances these recent planthopper outbreaks by impacting natural enemies (NE) of planthoppers [11–16].

The use of pesticides increased in Bangladesh by 200% from 1997 to 2000, 250% by 2006 and by nearly 500% by 2014 [17]. Major part of these insecticides has been used in rice field to pests [18]. Non-target organisms are susceptible to synthetic insecticides and these are also highly hazardous to environment [19–21]. In addition to the use of synthetic insecticides, climate change and landscape change have also induced the disappearance of NE from Bangladesh rice plots.

Habitats of surrounding landscape of a crop field can influence the number of natural enemies [22, 23]. Other pest (such as disease) management options and their application time can also influence the abundance of natural enemies in a crop field [24, 25]. Landscape composition and configuration influence the abundances of pest and NE in a crop field [26]. Each landscape shows a unique spatial heterogeneity which indicates the uneven distribution pattern of an individual across a given area [27]. In geospatial language, the variogram refers to the degree of spatial dependence of a spatial random field or stochastic process which often used to analyze the spatial heterogeneity of a remote sensed image and their resolution [28]. Variogram is commonly used to analyze the spatial heterogeneity addressing their spatial resolution [29].

Specifically, landscape characteristics can influence pest and NE population in crop fields. Recently, remote sensing methods enabled rapidly collected surface monitoring for locale, landscape, vegetation, specific crop, water body, and animal population data. Because variogram inquiry of a local landscape recognizes and elucidates the ecological appearance [30], we used variogram analysis to identify impacts on the landscape characteristics that can also explain the pest and NE population abundance.

Understanding the landscape characteristics impact on pest or NE and their functional characteristics would be asset for making an effective pest management programme at local scales [31]. However, the description of the abundance of NE in different Bangladesh rice landscape categories remains elusive. Therefore, the objective of this study was to assess the abundance of NE in different rice landscapes to help design pest management strategies influenced by the different rice production seasons, types of production styles (i.e., small, household farmers vs large, non-household farmers) and categories of landscape-scale agro-ecosystems. In addition, variograms were used to analyze the landscape characteristics based on LANDSAT 8 images collection. To target this objective, we surveyed, recorded, and summarized the abundance of several NE species from different rice landscapes in Southern Bangladesh.

## Results

We have assessed four (4) different insect predators in the rice landscapes situated in Barishal Division of Bangladesh (Fig. 1). The predators are spiders (a general predators group), the green mirid bug (GMB, *Cyrtorhinus lividipennis* Reuter), an egg predator of planthoppers and leafhoppers of rice, the carabid beetles (CDB), predators of several kinds of planthoppers and leaffolder

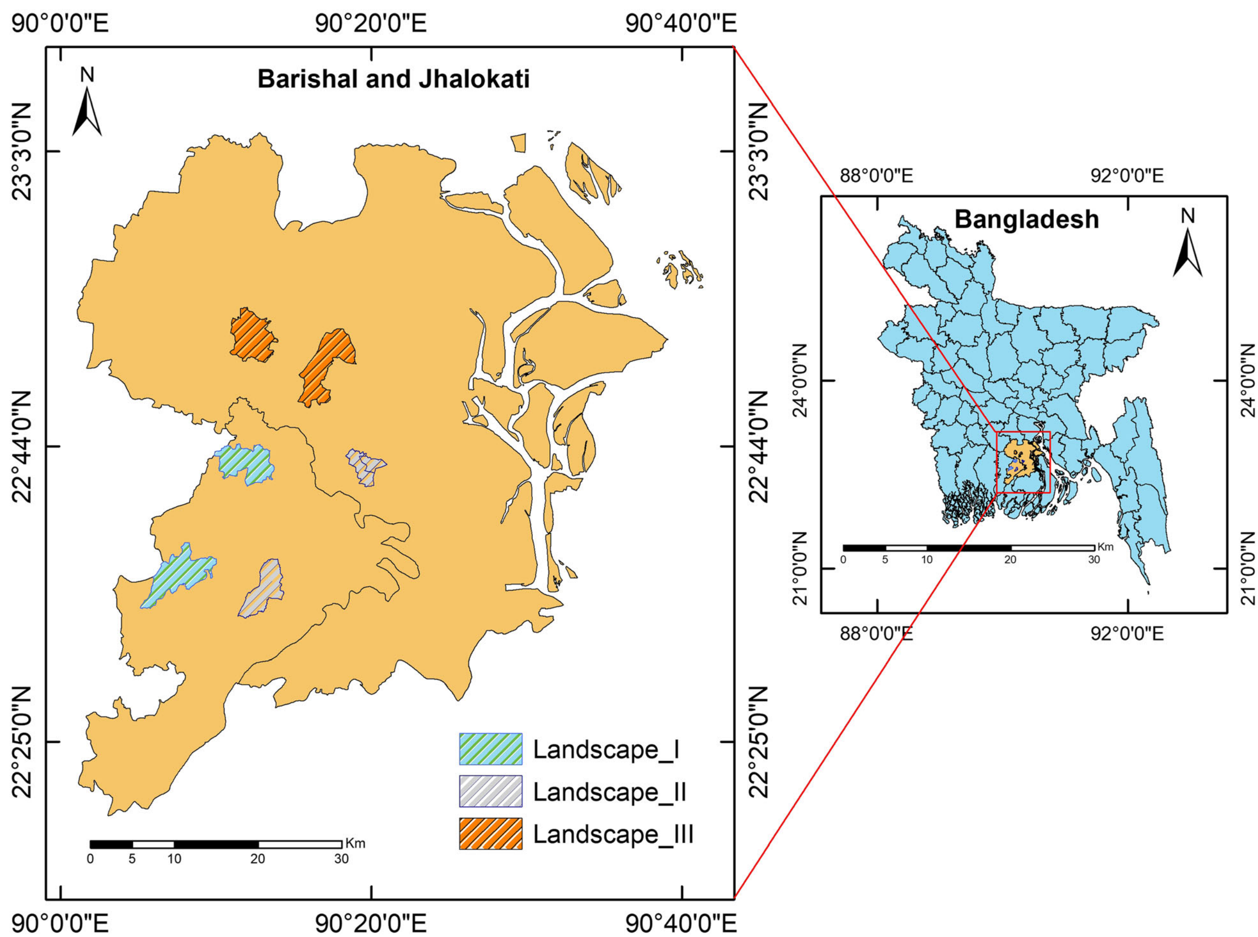


**Fig. 1** Map of the study location of Bangladesh, for the Barisal Division, with six unions containing the three landscape categories sampled for insects. All eighteen unions were employed for variography analyses

larvae of rice, and the staphylinid beetles (STPD, staphilinids), a generalist predator of the nymphs of planthoppers. The number of insect pest species found during this phenological stage while sampling NE was negligible (less than 3 insects per 20 complete sweeps), having no effect on rice yields. The sampled plots were also tracked up to harvesting stage in order to detect if a significant number of pests occurred after data recording. The investigated plots did not show any visual plot damage due to insect pests. But the number of NE population varied among the landscapes, and their population abundance is described below.

## Spiders

Spiders differed significantly across the three landscape categories. Landscape I showed the highest population numbers compared to other two categories (Fig. 2). For landscapes I and II, numbers were significantly higher in the rice plots than in the rice bund, while the highest population was found in the landscape I rice plot (see Fig. 2; $p = 0.001$). The spider populations also depended on the width of rice bund with a statistically significant trend for increasing populations with increasing bund width (Fig. 3) (Pearson's correlation, $r = 0.576$; $p = 0.050$). However, we did not find any correlation between spider numbers and the number of weed species in bunds (Pearson's correlation, $r = -0.119$; $p = 0.80$). The relative abundance of spider population also significantly differed among the three landscapes (Fig. 4).

## Green mirid bug (GMB)

Population of GMB differed significantly among the landscapes. Rice plots located in landscape I showed the highest populations compared to the other two (see Fig. 2, $df = 9$, $F = 167.58$, $p < 0.001$), while the lowest population was observed in the rice plots of landscape III. Similar numbers of GMB population were found in the rice bund of both landscape I and landscape III, with significantly fewer individuals observed on the rice bunds of landscape II (Fig. 2, $df = 9$, $p < 0.05$).

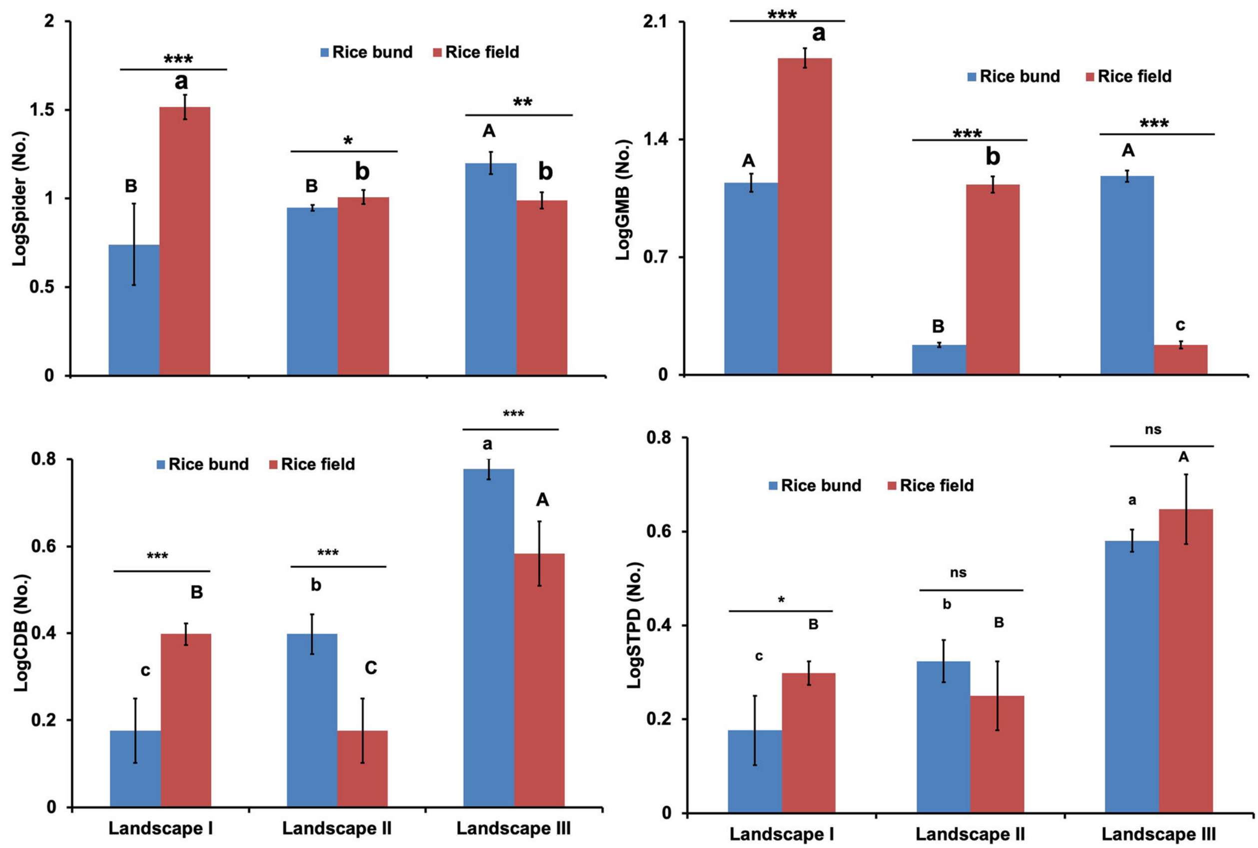


**Fig. 2** Abundance of spider, green mirid bug (GMB), carabid beetles (CDB) and staphylinid beetles (STPD) in three rice landscapes. Means followed by the same letter do not differ significantly at 5% level. The error bar represents the standard error. (***, ** and * indicate significant at 0.1, 1 and 5% level respectively; ns: non-significant at 5% level. Capital and small letters indicate the rice bund and rice plot in different landscapes respectively)

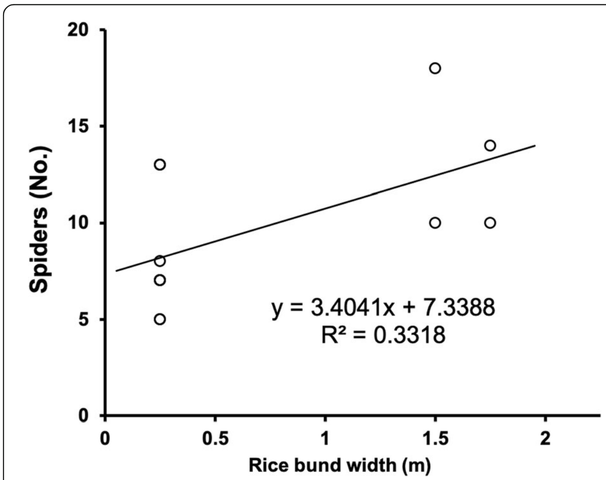


**Fig. 3** Effect of rice bund width on the spider individuals. Twenty complete sweeps were used to record populations from rice bunds

Populations of GMB differed significantly between rice plots and rice bund among all landscapes ($df = 9$, $p < 0.001$). The relative abundance of GMB population also significantly differed among the different landscapes (Fig. 4).

### Carabid beetles (CDB)

Populations of CDB significantly varied among all landscapes, with landscape III showing the highest numbers in the rice plots compared to the other two (Fig. 6 $df = 9$, $F = 167.58$, $p < 0.001$), and the least in landscape II rice plots. For rice bund, highest population of CDB was found in landscape III and the lowest population in landscape I. The CDB population significantly varied between rice plots and rice bund at each landscape ($df = 9$, $p < 0.001$). Like the spiders, the CDB abundance also depended on and increased with the width of rice bund (Pearson's correlation, $r = 0.423$; $p = 0.050$). But we did not find any significant correlation between CDB numbers and the number of weed species grown in bund (Pearson's correlation, $r = 0.119$; $p = 0.78$). The relative

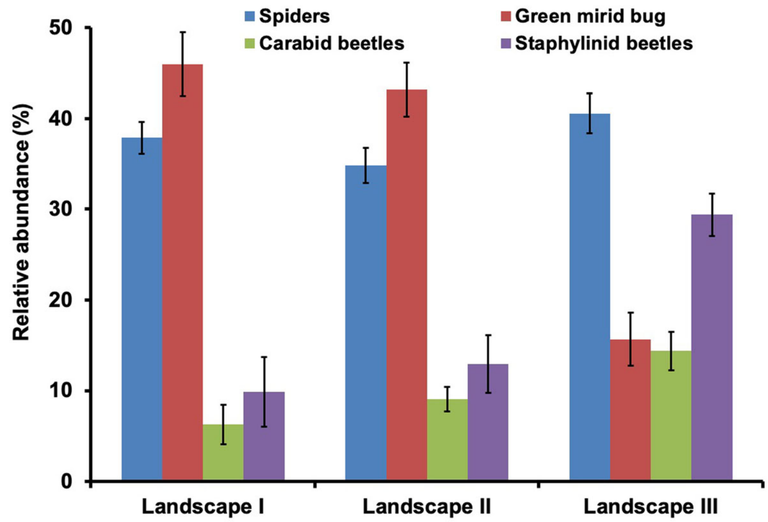


**Fig. 4** Relative abundance of four predators in three rice landscapes

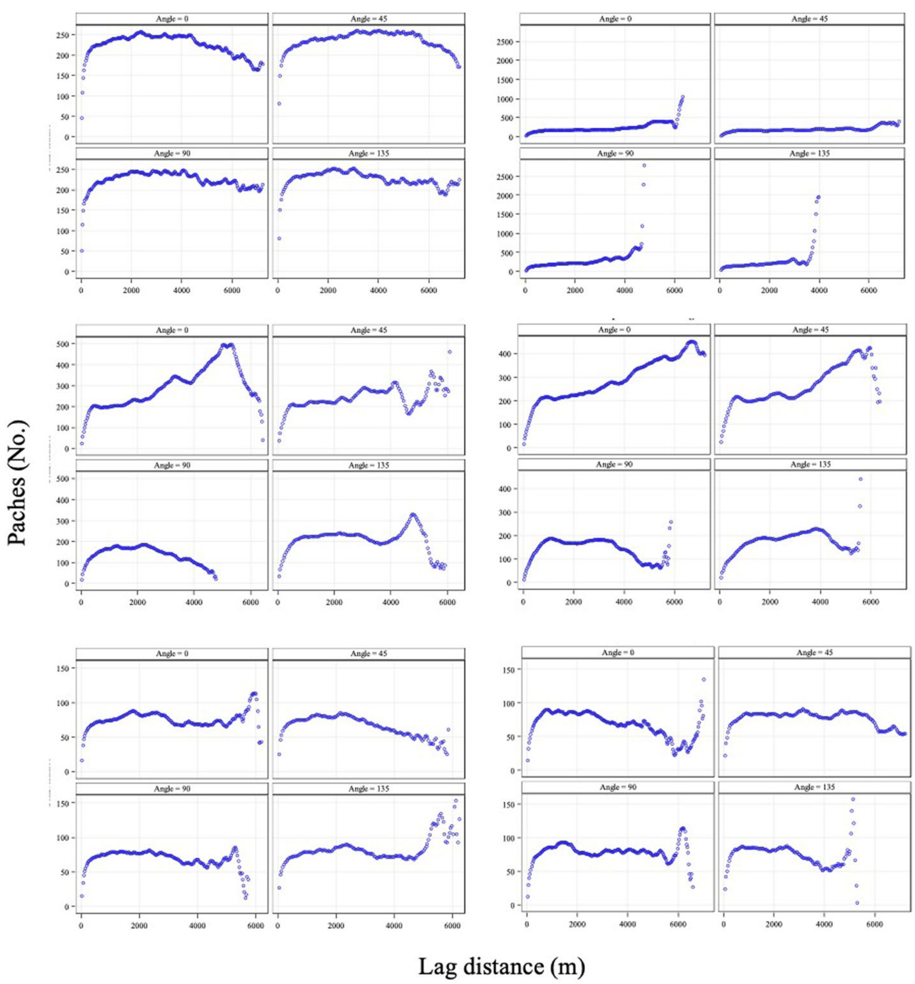


**Fig. 5** Empirical variograms in one direction for the RED spectral band of a LANDSAT 8 image of 30 m ground spatial distance per pixel, of six southern Bangladesh unions sampled for NE abundances

abundance of CDB also significantly differed among the different landscapes (Fig. 4).

### Staphylinid beetle (STPD)

Landscape III contained significantly more staphylinids than landscapes I and II. (Fig. 2, $df = 9$, $p < 0.05$). The rice bund in landscape III harbored the highest number of staphylinids with the lowest population numbers in landscape I. Staphylinids were not varied significantly in landscape I ($df = 9$, $> 0.05$) in contrast to the other two ($p > 0.05$). Staphylinid abundance in the rice bund neither depended on the width of the rice bund (Pearson's correlation, $r = 0.322$; $p = 0.481$) nor did we find a correlation between staphylinids and the number of weed species grown in bund (Pearson's correlation, $r = 0.243$; $p = 0.599$). There is no significant difference between plots and bunds for any landscape categories except landscape I (Fig. 2). The relative abundance of staphylinids also significantly differed among the different landscapes (Fig. 4). Studied landscape showed different diversity of predators. Shanon diversity index of landscape I, landscape II and landscape III were 0.646, 0.585 and 0.629 respectively.

### Variography analyses

Variography describes spatial continuities within data and can be used as a geostatistical method for analyzing topographic imagery [32]. For the purposes of this research, however, the variograms derived at each test area—subsetting out only the RED pixel attribute for estimating the empirical variogram—used a RANGE parameter large enough to span the breadth of each area, regardless of its size and shape. Hence, the variograms plotted show more undulation than typically found by other analysts, when only seeking to estimate a range distance where the SILL parameter reaches its initial plateau (Fig. 5). To understand how variography of a large areal extent can relate to landscape level characterizations, more liberty in the range attribute of each variogram of each of the six test areas was granted. Each test area is taken as one landscape based on the surrounding characteristics. Variogram analysis on remote sensing data determine spatial heterogeneity, providing insight into distinguishing spatial characteristics of crops and could be extended to multitemporal analyses [30, 33, 34]. The variograms of each landscape can explain landscape heterozygosity which could induce the insect functional diversity. Moreover, diversity indices of three landscape categories were also analyzed. Shannon diversity indices of landscape I, landscape II and landscape III were 2.057, 1.274 and 1.365 respectively. Similarity index of landscape I to landscape II, landscape II to landscape III and landscape I to landscape III were 0.60, 0.68 and 0.48 respectively. We also determined the individual rarefaction diversity index between two sites within each landscape category which indicated the similarity of two site landscape categories (Fig. 6). This result indicates that two sites have similar landscape which were considered as landscape replicated in our study. Based on Shanon index, we found that a positive correlation ($p = 0.0213$, $r = 0.9862$) existed between landscape and predator diversities (Fig. 7).

## Discussion

The presence of NE is a vital component of Integrated Pest Management (IPM) approaches for control of crop insect pests. In this sampling experiment, we sought to quantify NE abundance in three distinct rice landscapes. We found that NE abundance could vary significantly among the sampled landscapes in both the plot and bund. While such variation across landscapes might arise due to environmental factors (including temperature, landscape elevations, historical plant communities, new cultivated plant communities, local characteristics, soil characteristics, weather forcings, etc.) or anthropogenic factors (including cultural or pest management practices) remains to be characterized exactly.

While high abundances of GMB ($110 \pm 18.26$ per 20 complete sweeps) were found in landscape I rice plots in Protap ($p < 0.01$), no GMB prey—specifically brown planthopper (BPH), the white-backed planthopper (WBPH), or the green leafhopper (GLH)—were found in any abundance, despite sweeping and visual inspection for them. As such, the mechanism to explain the high GMB populations in landscape I remains elusive. Generally, GMB eat the eggs of prey laid in rice plot stems. Given the huge GMB population, the prey population was so small that we could not measure damage to any rice plant at the sample number sizes used. Variation in predator population can be explained differently, for instance, landscape structures might provide suitable hosting for specific predators and induce higher number of predators in rice plot. Landscape structures containing perennial habitats can support higher abundance of NE [35]. NE populations also can be influenced by such vegetational diversity [35].

In this study, landscape I contained abundant perennial habitat surrounding the rice plot. This abundant perennial habitat and higher vegetational diversity [22, 36] likely supported the high GMB abundance. Alternatively, a landscape may have a large proportion of semi-natural habitat and be otherwise dominated by a single, semi-natural land-cover type such as forest. In this experiment, the presence of a semi-natural habitat or abundant perennial habitat seems better predictor of GMB abundance than habitat diversity [22]. Aquatic weeds (water lattuce) growing in the narrow canal close to the landscape I rice plot also harbored the mirid bug

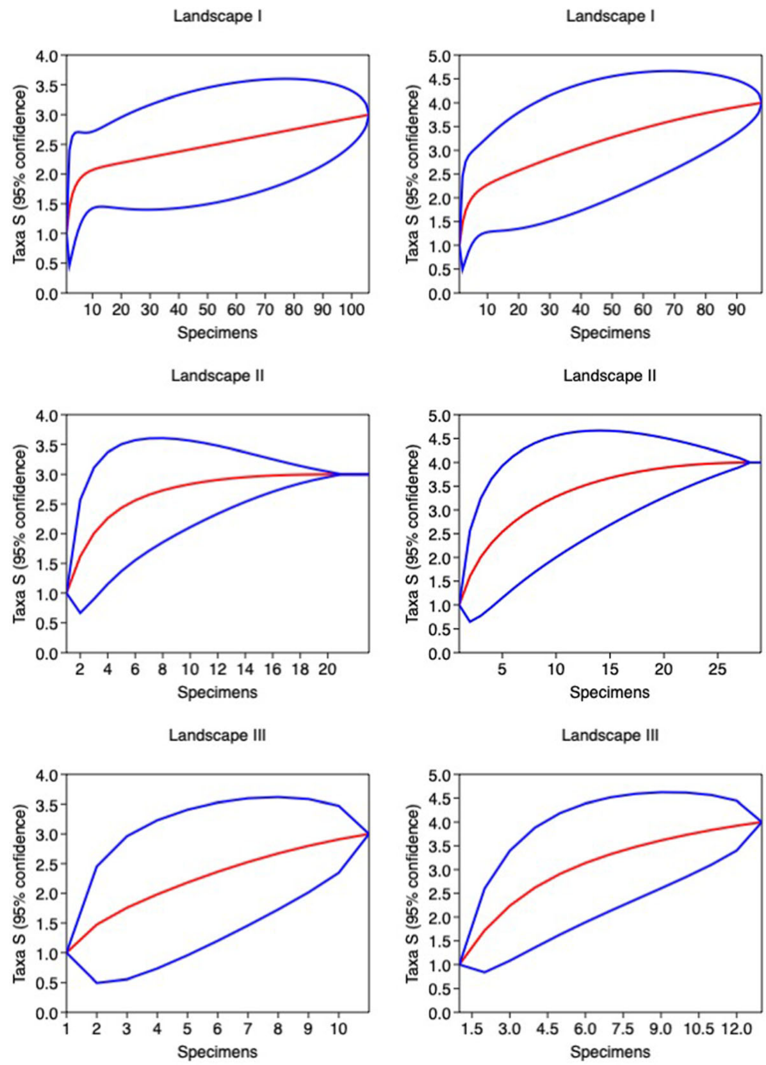


**Fig. 6** Individual rarefaction/species accumulation curve of diversity for two sites within each landscape category. Diversity index was analyzed using PAST software. Upper panels indicate site one representing landscape I, middle panels indicate studied site two representing landscape II, lower panels indicate studied site 3 representing landscape III

population. Collecting water lettuce supports the green mirid bug rearing in lab (personal investigation).

Similarly, the highest number of spiders was found in landscape I. This may be an effect of the landscape composition/ecosystem, including the surrounding environmental conditions. Higher numbers of spiders were found in rice plots rather than bunds in both landscape I and landscape II, with the reverse in landscape III. Given that population numbers depended on rice bund width (Fig. 3), and the rice bunds were smaller in landscape I and landscape II (approx. 25 cm) than in landscape III (75-150 cm, or 3–6 times wider). The bund margins provide habitat and resources for arthropods such as a ground dispersing predators, large *Pardosa pseudoannulata* spiderlings and adults [37]. While the wider spaces of rice bund also host greater number of weed species, which could induce higher numbers of spiders in landscape III bunds, our study did not demonstrate any significant correlation between NE populations and the number of bund weed species (df = 8, $p > 0.05$). However, more research is required to conclude this.

The populations of carabid beetles and staphylinid were higher in landscape III than landscape I. This variation may arise, once again, from the effect of landscape characteristics, including surrounding environmental conditions or man-made traditions. Agricultural landscapes used to produce existing or newly introduced crops for mitigating nutritional and food security issues for increasing human population can influence predators at local scales, given that some crops might provide a more (or less) suitable habitat than previous ones [35].

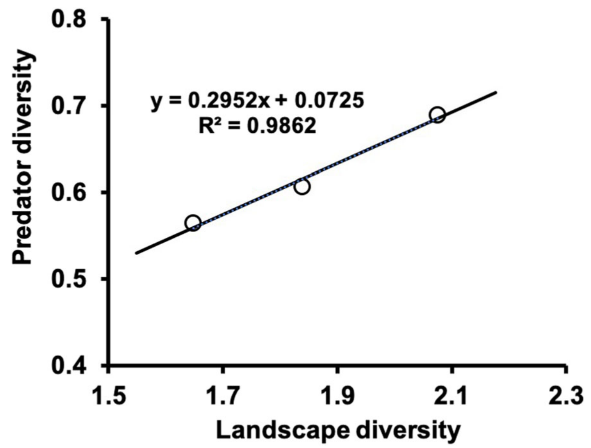


**Fig. 7** Relationship between landscape diversity and predator diversity. Diversity was analyzed based on Shanon index

We also applied a variogram model to characterize critical spatial relationships between neighboring locations [38]. Modeling from the observed sample data, the %population/plot estimates of four predatory insects were further refined. Spider and mirid species, carabid beetle and staphylinid beetle varied by region, and the process of variogram modeling and estimation was repeated for each region. With mirid bug population, the region was applied to target more specifically those areas in which the species was more dominant. Geospatial analysis involving some methods/tools including variogram (often so called semivariogram) to identify the spatial heterogeneity of an area of interest. At the initial stage, we conducted variogram analysis (Fig. 5) indicating that more data are required. In our variogram analysis, we applied only the RED pixel attribute for calculating the empirical variogram regardless of its size and shape. Spatial variability indicated by the sill increased with wavelength and reaches its peak in red band. After that sill strongly reduced and reached at near-infra red band. It indicates that red band shows wider spatial variability. However, blue and green bands show comparatively lower spatial variability of a given area. This is supported by other reports. Wider variability was found in near-infrared bands at natural landscapes than blue and green bands [28]. But, near-infrared bands represent lower heterogeneity over the visible wavebands in case of urban landscape [28].

Measurable metrics (11) of each landscape were considered to analyze the change of landscape at experimental sites. Patch richness represents the landscape composition and configuration. Number of total patches enhanced from 100 to 500 at landscape I, indicating that the landscape I has the spatial heterogeneity in this area (Fig. 5). This spatial heterogeneity harbored higher abundance of GMB in landscape I rice plot. The value of the largest patch index also decreased greatly in other landscapes (Fig. 5). Type of patches of a given area represent the all metrics of landscape and it has no sensitivity to a single metric and ecosystem compositions is used to track the changes of landscape characteristics at locale [39]. Landscape which has spatial heterogeneity could influence the ecosystem functioning such as prey-predator interaction. Therefore, altering the spatial heterogeneity of a specific landscape also influence the functional food web systems. Li and Reynolds [40] investigated the effectiveness of landscape metrics to quantify the spatial heterogeneity which influence the functional diversity at local scales. Both diversity indices and similarity index among the three landscape categories confirmed that heterozygosity existed in the studied landscape which might explain the variation of predators' abundance in each landscape. Our study showed that a positive relationship existed between landscape diversity and predator diversity (Fig. 7). This indicates that higher landscape diversity habitats more species.

Future research would benefit from collaboration between Bangladesh rice and Mid-South, USA cotton entomologists around analyzing public domain imagery—including imagery scaled not only over years but also across months within years, and across different areal extents—in comparison to on-the-ground count data of NE and pest abundances. Along with these kinds of data layers that characterize the temporal resolution of the information, care must also be given to spatial and spectral resolutions of the remote sensing layers where available. Our early collaborations show considerable opportunity for learning more about agriculturally distinct landscapes (and the arthropod fauna of interest) in Bangladesh, ultimately towards achieving the broadest objectives of this research: to evaluate the impact of landscape heterozygosity on the abundance of predators or rice insect pests.

## Conclusion

In this study, we characterized the spatial heterogeneity of landscape in terms composition and configuration that surrounded the experimental plots and analyzed the changes of this spatial heterogeneity can influences the abundance of insect predators. We integrated the methods of landscape indices and variograms based on categorical maps in insect functional diversity study. Managed habitats enhance the number of natural enemies at a local scale. Therefore, among the different landscapes, natural enemies are often differently prevailed between the rice plots of plots than the plot edge habitat of the rice bund. In contrast, overall natural enemy levels in equivalent habitats may be related with proportional abundance of semi-natural, dominating, single habitat types found different within each landscape category. Predator individuals in rice plots explained by analysis of adjacent environmental components. This indicates that landscape characteristics induce predators in crop field. It recommends that expecting the increased bio-control services for rice insect pests will require a focus on manipulating overall landscape structure. Knowledge of such a complex situation among landscape characteristics, pest and predators will motivate farmers and scientists to make a more effective pest management package especially suited to a specific landscape. This study concludes that natural pest control service providers such as predators/natural enemies choose a specific landscape metric which provide food and shelter for their survival and integration of spatial analysis would be aided to rapid identification of local characteristics for a specific predator. However, more studies including multiple years are required to confirm the impact of landscape on pest suppression mechanism in a specific area.

## Methods

Sampling experiments were conducted in three categories of landscape in Southern Bangladesh demonstrated in Fig. 1. The map was constructed using ArcGIS Advanced Desktop 10.7.1 (ESRI single user, ArcMap 10.7.1). Each landscape category represents a unique type and is sufficiently describable to permit replication of each category. We categorized each landscape as within a buffer zone characterized both by surrounding features and characteristics found within each buffer. We experimentally replicated each landscape two times (Fig. 1).

### Landscape I

Rice plots in this category are typically surrounded by big and small fruit trees or forests (such as deciduous and coniferous trees). The entire rice plots, here, are enclosed by densely perennial habitats, having fewer kinds of annual crops and lower vegetational diversity. The perennial habitats are found in close proximity to rice plots, with a range of distances from 10 to 30 m. The main feature of this landscape is the presence of small, narrow (so called canal) drainage flows between the rice plots and (concrete) roads, which always flows and has some weeds growing in the canals. The canals are connected to rice plots, which were very muddy types. The irrigation system of this landscape type consists of a shallow tube well. The width of rice bunds surrounding rice plot range between 25 and 35 cm and separate one smallholder plot from another one. Landscape I replicate were selected near Protap, in the Rajapur Upazila Union, and the Jhalokathi Sadar Union of southern Bangladesh and were of similar structure and composition by visual interpretations. The specific location of this landscape is presented in Fig. 1.

### Landscape II

This category consists of rice plots, homestead trees, and a rain forest, containing both small and big trees. The landscapes are located the Nalchity Upazila, in the Jhalkati and Barisal Sadar Unions of southern Bangladesh, characterized by less muddy rice plots found near roadsides, with a few fruit and forest trees found around the rice plots and planted along the roadside. Any nearby perennial habitats were very far from the rice plots compared to Landscape I, with distances between 100 and 200 m. There are no canal or drainage systems in this landscape, and the irrigation system is comprised of deep tube wells. The specific location of these landscape replicates is also shown in Fig. 1.

### Landscape III

This third category was selected near the Babuganj and Wazirpur Upazilas in Barisal District of southern Bangladesh (see Fig. 1). It features an irrigation system different from the other categories, namely, a buried irrigation system, with rice plots surrounded by some local fruit and other cultivated trees, but slightly farther away from the rice plots. Any areas of perennial habitats were very far from the rice plots, with distances between 200 and 400 m. The roads were also 200–400 m more distant from the rice plots than any roads of the other two landscape categories. Small, narrow trees were also found alongside the roads. A narrow, small canal was also present in this landscape but 300–400 m away from the rice plots. Entire rice plots were divided into two separates, but big, parts by a wide walking bund, with an additional irrigation channel located on it. Shannon diversity index was calculated of these three landscapes based on composition. Shannon (or Shannon–Wiener) index is defined as $H = -\sum_{i}^{S} p_i \ log(p_i)$, where pi is the proportional abundance of species i and S the total number of species [41]. Similarity index (landscape I to landscape II, landscape II to landscape III and landscape I to landscape III) was also determined based on composition. In addition, Shanon index of predators at each landscape was also analyzed and explored any relationship with landscape diversity. The analyses are implemented in vegan [42].

Rice plots from each landscape selected for study ranged 15–20 ha in area. This area contained 50–70 plots and each plot was separated from each other by bunds. These characteristics existed in each sampling landscape, except for Landscape III. In the Landscapes I and II, each small plot was occupied by one smallholder rice farmer, who maintained plots according to improved rice production technology. The size of farmer plots varied from 1500 to 2500 $m^2$. The plot size in

Landscape III ranged between 1000 and 2000 $m^2$ and were farmed by smallholder farmers. The plots for all replicates selected to record arthropod populations were transplanted with BRRI dhan29 (a mega-rice variety in Bangladesh). In each landscape, four to six plots were considered for data collection.

For transplanting BRRI dhan29 in selected rice plots, farmers raised seedlings in a seedbed. Seedbed management was performed according to the traditional farm practices [43]. Before transplanting seedlings into candidate sample plots, land was well prepared according to the common practice of wetland soil preparation followed by laddering. Laddering is the cultural farming practice where the ladder is used to break down clods and level the plot once or twice after ploughing. Seedlings 35–45 d old were transplanted in selected rice plots during the *Boro* rice cultivation season in 2015–2016. Standard transplanting space ($20 \times 20\ cm^2$) was maintained. Fertilizers containing N, P, K, and S were applied at the rates of 82, 15, 38, 10.6 and 2.7 $kgha^{-1}$ respectively, using urea, triple superphosphate (TSP), muriate of potash (MOP), and gypsum. The total amount of TSP, MOP, gypsum, and 1/3 of the urea amount were applied during the final land preparation period. The remaining urea was top dressed in two equal splits at 20 d after transplanting (DAT) (or the early tillering stage) and 40 DAT (or the maximum tillering stage), synchronized with irrigation or wet soil conditions, because the sampling experiment was conducted under irrigation conditions. Pesticides (Virtako 40WG @ 75 g/ha) were applied two times in all rice plots across the tested landscapes. Similar amounts of pesticide were thereby received by each rice plot.

Arthropod populations were recorded from 4 to 6 plots of each replicated rice landscape category (4–6 plots × 6 landscapes). Two landscapes of each category were considered for this study with random sampling conducted twice. Arthropod populations were collected from both the chosen rice plot, and its adjoining rice bund, using a sweep net. Durable insect sweep nets easily collected insects from grass, fallow land, brush, and the rice crops. In total, 2 × 20 complete sweeps were taken to collect insect pests and their NE at maximum tillering stage of the rice crop at each sample plot, because that stage of rice harbors a wider number of arthropods [44]. The collected insect pests and NE were sorted, identified, counted, and written onto a data collection sheet for every sampled plot.

Each bund was covered by numerous weed species. The number of bund weed species were also recorded, although individual weed species were not identified taxonomically. Instead, we calculated estimates of the total number of weed diversity as found on each bund. The width of each rice bund was also recorded using a measuring scale. The plot used to collect arthropods using sweep net was also examined by rice hills (for a total of 100 hills/sampled rice plot) in order to make additional observations on infestations by insect pests that stay in the lower part of the plant. The sampled insect pests observed in the tested plots in each landscape were negligible; only NE populations are described here.

Relative abundance of NE populations was calculated using the following equation:

$$Relative\ abundance\ (\%) = \frac{Total\ No.of\ individuals\ of\ each\ species}{Total\ No.of\ individuals\ of\ all\ species} \times 100$$

Analyses of variance (one-way ANOVA) was conducted using landscape category as the explanatory variable. Means were compared by Tukey's test among the landscapes ($P < 0.05$). Summary statistics of one-way ANOVA conducted considering the impact of landscapes on the abundance of four predators are presented

**Table 1** Summary statistics of one-way ANOVA conducted in this study the know the impact of landscapes on the abundance of four predators in a rice field

| Predator | Source of variation | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Spiders | Between Groups | 485.309 | 2 | 242.654 | 4.374 | .027 |
| | Within Groups | 1109.561 | 20 | 55.478 | | |
| | Total | 1594.870 | 22 | | | |
| Green mirid bug | Between Groups | 7452.873 | 2 | 3726.436 | 8.707 | .002 |
| | Within Groups | 8131.900 | 20 | 427.995 | | |
| | Total | 15,584.773 | 22 | | | |
| Staphylinid | Between Groups | 85.420 | 2 | 42.710 | 7.836 | .003 |
| | Within Groups | 109.015 | 20 | 5.451 | | |
| | Total | 194.435 | 22 | | | |
| Carabid beetle | Between Groups | .157 | 2 | .079 | .235 | .793 |
| | Within Groups | 6.712 | 20 | .336 | | |
| | Total | 6.870 | 22 | | | |

in Table 1. The paired *t*-test was also performed to analyze the effect between rice plot and bund. Data were transferred to logarithm scales in order to homogenize the variance. Pearson's correlation analysis was used to determine the correlation coefficients between the NE populations and rice bund's width and the number of weed species growing on the bund. All statistical analyses were done using SPSS software, Version 16.0. Bray Curtis similarity indices and individual rarefaction indices were determined among the two sites within each landscape wising PAST software [45].

Lastly, a LANDSAT 8, true color satellite image in TIFF format, (labelled, LC08_L1TP_137044_20161130_20170317_01_T1) for late November, 2016, was obtained from the United States Geological Survey (USGS) website for variography analyses. It was hypothesized that variograms at the test area extent of the six sampled landscapes and twelve more non-sampled, non-classed nearby areas for comparison could be useful in aiding landscape classifications of the other administrative divisions of regional test area of southern Bangladesh. ERDAS IMAGINE® 2016 and ESRI ARCGIS® 10.2, as well as SAS® software for PROC VARIOGRAM, were utilized to process and analyze the RED spectral pixels contained within the polygon feature layer of the selected test areas (Fig. 1). A 100 × 100 - pixel subset was chosen randomly from an aerial multispectral image which contains three wavebands, Green, Red and near-infrared (NIR). Green, Red, NIR and Normalized Difference Vegetation Index (NDVI) datasets were imported into SAS software for spatial analysis. The November 2016 date was selected for its cloud-free characteristics and because it was not closely associated with the sampling times of the plot survey data, in order to examine how non-seasonal information from satellite platforms may aid the ground survey results and characterization of the sampled landscape classes.

#### Abbreviations

BRRI: Bangladesh Rice Research Institute; GMB: Green mirid bug; CDB: Carabid beetles; STPD: Staphyllinid beetle; SAS: Statistical Analysis Software; USGS: United States Geological Survey; SPSS: Statistical Package for the Social Sciences; ANOVA: Analysis of variance; NE: Natural enemies; BPH: Brown planthopper

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#### Authors' contributions

MPA, MMMK, SSH, SA, NA design experiment; MPA and MMMK collected data; MPA, MMK, SA compiled the data; SSH, NA organized funding, sampling expeditions and availability of materials. MPA, XQ analyzed the data; MPA wrote the original manuscript; NA, XQ, BP revised and edited the manuscript; BP edited English language and interpreted the results. All authors have read and approved the final manuscript.

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#### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

#### Ethics approval and consent to participate

Research did not involve any human participants, human material, or human data.

#### Consent for publication

Not applicable for this research.

#### Competing interests

Authors declare that they have no competing interest.

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