Analysing diversity patterns of Pyraloidea (Lepidoptera) along the elevational gradient in the East Himalaya of India: Richness, Turnover and range size components

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Abstract

Elevational gradients provide opportunities to study underlying mechanisms shaping community assembly and help to predict ecosystem response to climate change and the impact of local climate on species diversity. Moths with their vast diversity and abundance represent one of the most diverse groups of insects serving significant roles in various ecosystems. Assessing distribution of moths along elevational gradients is important for planning conservation policies. Large elevational gradients are known for their species enrichment capacities making them important conservation hotspots, especially because they can allow for redistribution of species in response to climate change. Herein, we investigate the richness, turnover and range size patterns of Pyraloidea along a mountainous altitudinal gradient of 200m-3500m in the East Himalaya. Sampling was done manually at different altitudinal locations (separated by 500m elevation) with the help of light traps resulting a total of 357 morpho-species of Pyraloidea represented by 14 families. Species richness pattern of Pyraloidea showed a mid-altitudinal peak at 1500m and the highest altitude recording the lowest richness. The species turnover patterns showed peak turnover at the lowest and highest altitude, with lowest turnover value at mid-altitude. However, the altitudinal range size increased with increasing altitudes. Different sub-families reported significant difference in their altitudinal range, with Spilomelinae and Epipaschiinaeare found to be present at every altitude while Lathrotelinae and Galleriinae were restricted at 200 m and 1000 m, respectively. The response of Pyraloidea species to altitude shows that they are sensitive to climatic variables and the results of this study may serve as a baseline for future climate change investigations with Pyraloidea as a model system.

INTRODUCTION

Elevational gradients are known to limit organism’s spatial and temporal distribution (Merriam 1890; Terborgh 1977; Yu 1994; Fernandez et al. 1995; Lieberman et al. 1996) and are among the most potent natural gradients for assessing ecological and evolutionary responses of biota to abiotic stimuli (Körner 2007).Currently, the urgency to register and understand patterns in species richness is getting more and more important as the biodiversity threats looms large (Wilson 1992) and also considering the context of global warming (Parmesan 2006).Elevational gradients play important roles in maintaining high regional diversity and allow species to redistribute in response to climate change. In the tropics, larger elevational gradients should be prioritized for biodiversity conservation owing to their species enrichment. Understanding overall species richness patterns at biogeographical scales enables our understanding and conservation of biological diversity better (Vetaas and Grytnes 2002).

Studies on species richnessalong the elevational gradients conducted for a multitude of taxa in various regions globally (Bhattarai and Vetaas 2003; Bhattarai et al. 2004; Carpenter 2005; Flores et al. 2018; Fontana et al. 2020)revealeda range of diversity patterns (Rahbek 1995; Fontana et al. 2020). Various environmental and non-environmental factors, especially climate, geography, biological, geometric constraints and historical factors are found to play significant role in shaping the biodiversity gradients along elevation at greater scales (Rosenzweig 1995; Lomolino 2001).Of the different known diversity patterns along elevational gradient, mid-elevational peak and monotonically decreasing pattern are frequently observed or documented for various taxa and habitats (MacArthur 1972; McCoy 1990; Stevens 1992; Olson 1994; Rahbek 1995; Brown and Lomolino 1998; Fleishman et al. 1998). Rahbek's (2005) findings reveal, mid-elevation peaks were recorded for around 50% of the studies, 25% supported a monotonically decreasing trend, and the remaining 25% indicate alternative patterns in species richness along the elevation gradients.The non-generality in the elevational species richness patterns may be a result of differences in spatial design between studies, including grain size choice and the extent and proportion of gradients sampled (Rahbek 2005). Several empirical studies on elevational richness patterns have implicitly suggested that mid-elevational peaks are simply a result of mid-mountain turnover between lowland and highland communities (Shepherd and Kelt 1999; Nor 2001; Herzog et al. 2005).

Species turnover is another important parameter for evaluating biodiversity.It measures the rate of change in species composition along predefined spatial or environmental gradients. Regions having elevated species turnover are assumed to harbour high diversity (Clements 1916; Whittaker 1960, 1967; Brown and Kodric-Brown 1977; Wilson and Shmida 1984; Lennon et al. 2001). In-spite of recent reawakening of interest in turnover and beta-diversity indices (Koleff et al. 2003; Legendre et al.2005; Baselga 2010; Tuomisto 2010a,b; Legendre 2014), few empirical studies tried to statistically link the common assumption of concordance between turnover and richness patterns along the elevational gradients (Lennon et al. 2001), each using separate methodology for assessing turnover, including spatial clumping of lower and upper range endpoints (Shmida and Wilson 1985; McCain 2004; Herzog et al. 2005; Naniwadekar and Vasudevan 2007), diversity partitioning (Beck et al. 2012) and beta-diversity indices (Mena and Vázquez-Dominguez 2005; Dehling et al. 2014; Fattorini 2014). Due to the difference of methodology and analysis grain (e.g., 100, 250 and 500m elevational bands) various patterns of elevational turnover are evident like multiple peaks, predominately at mid-elevations (Herzog et al. 2005; Mena and Vázquez-Dominguez 2005; Levanoni et al. 2011), others appear to be increasing (Rahbek, 1997), bimodal or without any pattern (Mena and Vázquez-Dominguez 2005). Nonetheless, our knowledge about turnover hypotheses is limited and presently, we do not know if there are repeated and consistent patterns of elevational turnover, as there are for richness.

Over the time, numerous hypotheses have been suggested for explaining variation in species richness with increasing elevation. One such hypothesis known as Rapoport’s elevation rule (Stevens 1992), states about the positive correlation between elevational range (i.e., the range between minimum and maximum level of occurrence) of species with elevation i.e. the elevational range of species at lower elevations are generally smaller than at higher ranges (Rapoport 1982; Stevens 1989). It is hypothesised that the higher elevation climate is more variable compared to the lower elevations thus, higher elevation species must be able to endure broader range of climatic conditions and thus, greater variability leading to broader elevational ranges. In case of moths, Rapoport’s rule have yielded more or less mixed results, with some supporting the rule in case of Crambidae (Chen et al. 2022), Geometridae (Seifert et al. 2022; Brehm et al. 2007;) and Sphingidae (Grünig et al. 2017)while some indicate otherwise (Beck et al. 2016; Toko et al. 2023).

The Himalayan region is counted as one of the global biodiversity hotspot areas(Fu et al. 2022). However, studies regarding altitudinal distributions and Rapoport's rule have seldom been investigated in this region (Choi 2007; Beck et al. 2007; Sanyal et al. 2017; Dey et al. 2015). There are a very few studies exploring the link between species richness and elevation, and also testing the Rapoport's rule in insects (Lawton et al. 1987, Fleishman et al. 1998). Particularly in the case of Pyraloidea, no study has been undertaken to investigate species richness along elevational gradient in the Himalaya from India. The Pyraloidea, including its two families i.e. Pyralidae and Crambidae comprise 16, 379 species in 2,117 genera (Regier et al. 2012), are the third most ecologically diverse and species rich radiations in the order Lepidoptera. In India, 1695 species in 509 genera of Pyraloidea are reported (Singh et al. 2022). Pyraloids can be diagnosed by their proboscis being basally scaled and presence of a paired tympanal organ on the second abdominal sternum, bearing conjunctiva and a tympanal membrane having sensory scoloparium (Munroe and Solis 1999).The immature stages of Pyraloidea exploits a wide range of feeding behaviours such as, detritivory, coprophagy, predation and parasitism also, numerous pyraloid larvae are habituated to thrive in aquatic habitats (Yen 2004; Mey and Speidel 2008; Solis 2008). Pyraloidea have been used as model organisms in various ecological studies including biodiversity and community ecology (Fiedler and Schulze 2004; Yamamura et al. 2006; Beck et al. 2011; Tao et al. 2008a, b), population ecology and management (Arthur 2008; Oppert et al. 2010), behavioural ecology (Lewis and Wedell 2009; Lewis et al. 2011), genetics and pheromone communication system evolution (Roelofs et al. 2002; Lassance 2010; Fuji et al. 2011), co-evolution of parasitoid–host (Eliopoulos and Stathas 2003; Roberts et al. 2006; Niogret et al. 2009), development and physiology (Deniro and Epstein 1978; Siaussat et al. 2008; Ukai et al. 2009; Yin et al. 2011). Pyraloid moths are mostly distributed in the tropics, but are also recorded upto the high arctic (Solis 1997), also from a research station in Antarctica (*Plodia interpunctella*Hübner) **(Câmara et al. 2022)**,and thus, is a suitable taxa for conducting research related to the diversity and richness along elevation gradients.In the present study, we specifically tried to answer the following questions: (1) how pyraloid moths are distributed along elevational gradient in the eastern Himalaya of India, mainly their richness and turnover patterns; and (2) what are the patterns of the range size distribution of pyraloid moths along elevational gradient.

MATERIALS AND METHODS

Study area

The study was conducted from 2019 to 2023 in the Western Arunachal Pradesh (District: West Kameng and Tawang) which falls under the biogeographic province of East Himalaya (Rodgers et al. 2000). The region has an elevational profile ranging from as low as 100 meters to more than 4000 meters. The climate shifts from being moderate in the north to warm and humid in the south. The yearly rainfall ranges from 2,000 to 8,000 millimetres, while the annual temperature fluctuates from below 0°C to 31°C. (Indian state of forest report 2019).The study was conducted at 35 different locations (Fig. 1) comprising 7 different elevational bands (200-3500m asl). The altitudinal difference between two consecutive altitude levels was 500 meter (± 50 m). At each altitude, a minimum of 2–3 different sites were surveyed so that maximum representation of the pyraloid moth community could be observed and studied. Also each collection site was sampled at least thrice for covering the majority of pyraloid moths at that locality.

Moth sampling and identification

Moths were sampled during three periods (October-November, 2019, April, 2021 to June, 2021 and again during May, 2022 to May, 2023). Moth sampling was done by using vertical sheet light trap fitted with Mercury vapour bulb (160 Watt) or actinic light tube (18 Watt) powered by portable generator. Light traps are the most frequently used survey methods for moths (Beck et al. 2017; Brehm et al. 2003;Maicher et al. 2020). Sampling was carried out from 17:00 hours till midnight12:00 hours, coinciding with peak activity period of moths.During the collection period various environmental variables like temperature, wind speed, humidity were also recorded using a multi-meter probe. Moths were collected individually using killing jars euthanized with Ethyl Acetate. Afterwards, the moths were pinned, stretched, dried, followed by sorting into morpho-species and finally preserved for identification. For identification of the moth samples, we followed various literatures,books(Yamanaka 1995, 1998, 2000), websites (Sondhi et al. 2024) and also through comparison with the collections housed at Zoological survey of India, Kolkata.

Statistical measure

Species richness

For calculating species richness of a particular elevational band, individual species richness of all the localities at each elevational bands were pooled together. Any change in gross taxonomic composition of pyraloid moth communities along elevational gradient is analysed by calculating the proportions of pyraloid moth subfamilies at each elevation based on occurrence from light traps. The sampling completeness of each sampling locations were analysed using iNEXT software (Hsieh et al. 2016). Our main purpose was to characterize the elevational patterns of dominant pyraloid species, providing a baseline for future work in this understudied region reflecting broad elevational patterns of dominant pyraloid moths.

Species turnover rate

Species turnover along elevational gradient is quantified between two consecutive elevational locations following Simpson’s dissimilarity (Simpson 1943):

$$\beta_{\mathrm{Sim}} = \frac{\min(b, c)}{a + \min(b, c)}$$

Where b and c are the number of unique species to any one of the elevation while, a is the number of common species to both elevations. Simpson's dissimilarity remains unaffected by the measured species richness difference from recorded samples(Lennon et al. 2001; Koleff et al. 2003; Baselga 2010), between neighbouring elevational bandswhich is necessary for an insightful examination of the actual relationships between species richness and turnover.

Calculation of species range size

The elevational range for each species was calculated by subtracting the lowest elevation from the highest elevational band where the species was reported to exist (species were considered to have a continuous distribution between their lowest and highest elevational occurrence). In order to avoid the statistical non-independence of our data, we employed the 'mid-point approach' as a process for measuring central tendency, as recommended by Rohde et al. (1993). The average value of the lowest and highest elevation from which the species was present was used to indicate the midpoint of species' altitudinal range. The mean elevational range of species present in each elevational band was estimated by calculating the mean of the elevational ranges of all species reported to exist in the band. When a specific site elevation was required for an analysis, we utilised the midpoint elevation of each band, and finally we regressed the mean altitudinal range against altitude.Finally, we also correlated both elevational range and mean elevation against elevational gradient for testing Rapoport's rule.

RESULTS

The present investigation, based on a data set of over 3000 individuals and 357 morpho-species of which 312 was identified up to species level, 44 upto genus level and only one upto subfamily level, revealed that pyraloids are distributed along a large elevational gradient starting from as low as 200 metersand going up to 3500 meters. We encountered all the foursub-families in Pyralidae and 10 sub-families of Crambidae.

Species richness

We found that the species richness of Pyraloidea is maximum around mid-altitude (1500m), revealing a hump shaped pattern i.e. peak (maximum) richness at mid elevation with reduced richness at the lower and higher elevations (Fig. 2).

Individually, species richness of Crambidae and Pyralidae is found to peak at 1500 elevation, a pattern as revealed by the Pyraloidea. However, pyralids showed a complete mid elevation peak, while the crambids showed a low plateau with mid elevational peak (Fig. 2). Among the subfamilies of Crambidae, Spilomelinaedominatedspecies richness, followed by Pyraustinae, Odontiinae, Acentropinae, Glaphyriinae, Musotiminae, Crambinae and Schoenobiinae. On the other hand, in Pyralidae,Epipaschiinaedominated species richness followed by Pyralinae, Phycitinae and Galleriinae.

Spilomelinae are represented at all the altitudes surveyed, whereas Pyraustinae, Odontiinae, and Acentropinae are reported from 200m to 2500m,Schoenobiinae from 200m to 1500m, Crambinae from 500m to 2000m,Glaphyriinae and Musotiminae from 1000m to 2500m and Scopariinae between 1500m and 2000m.Among Pyralidae,Epipaschiinaeare recorded from 200m to 3500m and Pyralinae are recorded from 200m to 3000m altitude, respectively, Phycitinaefrom 500m to 3000m, whereas Gallerinae is recorded only at 1000m altitude (Fig. 3)..

Species turnover

We found a moderate to low turnover patternin Pyraloidea.The turnover raterepresentedtwo peaks (highest turnover value) at the two extremes (200m vs 500m and 3000m vs 3500m) and lowest value is recorded at mid altitude (1500m vs 2000m) (Fig. 3). At the lower altitudes (upto 1000 m) the species turnover is around 50% indicating half of the species composition getting replaced either by species gain or loss with respect to the corresponding altitude. While, turnover values at the mid altitudes (1000-3000m) ranged around 21%-27% indicating about one-fifth to one-fourth of species being replaced compared to corresponding altitudes (Fig. 4).

Species elevational range size

We found that the mean altitudinal range size of pyraloid moths gradually increases with the increasing altitudes (Fig. 4) i.e. species at lower altitudes have much lower altitudinal range compared to the species at higher altitudes thus, showing that the community composition of pyraloid moths differs along the altitude.The highest and lowest elevational range of the studied species is given in supplementary file.

Present study revealed that Pyraloidea at higher altitudes exploits greater altitudinal range compared to species found at lower elevation and the average altitudinal range of sites is correlated with elevation significantly ($R^2 = 0.9896$), also the average altitudinal range of species showed significant association with increasing elevation. This reinstates that the mean species range size of Pyraloidea increases with increase in elevation.

DISCUSSION

Species richness

In our study, pyraloid species richness showed a hump shaped pattern, which is the most commonly recognized pattern across a wide range of insects (McCoy 1990; Kearns 1992; Olson 1994; Sparrow et al. 1994) and also for moth groups likeErebidae (Arctiinae), Pyraloidea, Geometridaeand Sphingidae (Bärtschi et al. 2019; Fiedler et al. 2008; Beck et al.2017; Brehm et al. 2005; Toko et al. 2023) thus, conforming mid-elevation peaks as a rule rather than exception. Species richness of Pyraloidea is found to peak at 1500m which is just below the actual mid-point of the gradient,a finding similar to that of Beck and Kitching(2009) who concluded that the species richness peaks are most likely to be located below the true center of the available elevation zones (i.e. distributions are right-skewed).

Regarding the Pyraloidea composition along the elevational gradient, Crambidae are found to be dominant atevery site studied along elevational gradient, with higher number of species than Pyralidae (Regier et al. 2012). This is expected, as Crambid comprise the majority of Pyraloidea. We found both Pyralidae and Crambidae gradually decreasing at higher altitudes, while a study from Podocarpus national park, Ecuador,reported increase in Pyralidae species anddecrease in Crambidae species at higher altitudes (Fiedler et al. 2008) and another study by Chen et al. (2022) reported monotonic decrease in Crambidae (Pyraustinae and Spilomelinae) abundance with increasing altitude.

In our study, we found Spilomelinae to be dominant at every location and all the other sub-families showed peak richness at mid-elevation and decreasing trend towards higher elevation except Galleriinae, Lathrotelinae and Scopariinae.However, astudy by Fiedler et al. (2008) found Scopariinae, Odontiinae, Galleriinae, and Phycitinae to be more dominant at higher altitudes, whereasPyraustinae, Acentropinae, Musotiminae, and Glaphyriinae were found to be more prevalent at lower elevations. Schoenobiinae reported at medium elevations (1800–2300 m), though in very low numbers. Crambinae, Chrysauginae and Epipaschiinae did not show any clear altitudinal pattern.

Anthropogenic activities (e.g. deforestation, forest resource extraction, settlements, grazing etc.) at lower and higher altitudes have affected the lower and upper mountainous slopes globally, compared to mid-altitudes resulting in the mid-elevations having the most forests (Nogués-Bravo et al. 2008) and also faunal diversity. This phenomenon is also considered to be responsible behind diversity peaks at mid-altitudes. Since the present study isfocused mainly on unprotected areas, anthropogenic impacts are expected to be more pronounced, and may have led to the results of this study.At mid-altitudes, the interplay between anthropogenic disturbances and natural habitats creates a wide variety of habitat mosaics leading to the greater amount of species richness.Furthermore, the regions at mid-elevations may have undergone less environmental and climatic fluctuation compared to the possible flooding of lower elevations due to high sea levels or glaciation at higher elevations during warmer and colder geological periods. The environmental stability of mid-elevations may have allowed more time for the development of local communities, as suggested by the effective evolutionary time hypothesis (Rohde, 1992). These factors, which work together rather than independently, can influence the distribution and biology of a species along an elevational gradient (Romdal & Grytnes, 2007).

Species turnover

We found community dissimilarity peaked at the lower (200m) and higher(3500m) elevations and minimum at middle elevation (1500m), which could be due to the species loss towards higher elevations and species replacement at lower elevations.Our study supports the results of Choi et al. (2022), whoreported that the higher altitudinal sites showed relatively higher dissimilarity but contradictsvarious studies with reporting of high species turnover at mid altitudes, indicating two different communities at low and high altitudes (Mena and Vázquez-Domínguez 2005; Nor 2001; Shepherd and Kelt 1999).

However, Kitching et al. (2020) reported that pyraloid moth fauna shows distinct higher and lower elevational assemblages differentiating between 600-800m elevation. Historically, no consistent pattern on species turnover along elevation is reported.Among some well recognized patterns (McCain and Beck 2016), multipeaked patterns are common at all spatial levels. This high variability in turnover patterns highlights the individualistic nature of the endpoints of species ranges on elevational gradients (Gleason 1926; Whittaker 1967; MacArthur 1972), which also advocates that every species is dispersed separately along the gradient, within its niche limitation, with respect to environmental factors that have varying effects on each species.

Over the years, little concordance is found between the patterns of turnover and richness along the elevational gradient (Herzog et al. 2005; Naniwadekar and Vasudevan 2007; Fattorini 2014).However, in our case the species richness and turnover components are found to be somewhat inversely related. Since the elevation exhibiting highest species richness showed lowest species turnover.Relation betweenspecies richness and turnover patterns are scale dependent, at smaller spatial grains (200 m) they are found to be unrelated while at coarser grains (800m) the relationships is found to be stronger. But at that scale (800m), patterns of turnover and richness are found to be quite coarse and quantitatively, correlations are weak to moderate in most cases(McCain and Beck 2016). In our study we considered a scale of 500m which could be a reason for the discrepancy between the richness and turnover component. Also, our failure to sample rare species of pyraloids in every locality, may have led to the inconsistent patterns of species turnover due to underestimation of the total pyraloid diversity.Additionally, since we sampled manually and not by automated traps like in most of the studies, chances of human error also can’t be ruled out. All these factors may have played a role in shaping the observed turnover and richness patterns of Pyraloidea.

Numerous hypotheses have been proposed for explaining the elevational patterns of species richness, including biological, ecological, climatic, geographic and historical factors (Rahbek, 1995). Increasing elevation leads to changes in various abiotic and biotic factors, which can affect the distribution of moths. These factors include temperature, primary productivity, precipitation, habitat area, habitat complexity, food availability, interspecific interactions, UV index, humidity, and the partial pressures of O_2 and CO_2 (Körner, 2007; Rahbek, 1995). Additionally, different pyraloid moths exhibit preferences for specific niches, life history strategies, adaptive capacities, and tolerance levels, all of which likely influence their distribution along diverse environmental gradients. All these factors combined have played a role in the richness and turnover patterns of pyraloid moths in the eastern Himalayan region. While, in our study we only aimed at deciphering the richness and turnover patterns of Pyraloidea and thus we didn’t analyse in detail the biotic and abiotic factors responsible in influencing the distribution patterns of moths. Studying in detail the effect of these factors in Pyraloidea distribution will give us a detailed picture of factors primarily driving Pyraloidea distribution in the region.

Species elevational range size

We found that the species recorded at high altitude displayed broad altitudinal range compared to low altitude species and the average altitudinal range of sites is significantly correlated with elevation

(Fig. 4). The pattern is known as Stevens Rule (Stevens 1992) and can be explained on the basis of differences in range of climatic conditions experienced by the organisms along the elevational gradients at higher altitudes (Fernández and Vrba 2005; Gaston and Chown 1999; Morin and Lechowicz 2011).

Our study directly supports Rapoport's elevation rule.Similar results were obtained in case of European and tropical geometrid moths (Seifert et al. 2022; Brehm et al. 2007; Toko et al. 2023), hawk moths (Grünig et al. 2017), crambid moths (Chen et al. 2022) and also in case of various insects like grasshoppers, butterflies, ants etc. (Fleishman et al. 1998; Sanders 2002). While Beck et al. (2016) found moths in general not supporting Rapoport's rule. Additionally, majority of insect studies (64%) and invertebrate (e.g. spiders, land snails) and non-tree plants related studies (57%) were found not supporting Rapoport's elevational rule (McCain and Knight 2013). Wider distribution range of high altitude species suggests that they travel regularly to the lower zones, resulting in higher species richness at mid-altitudes (Stevens 1992), which might serve as sinks for high-altitude species during harsh environmental conditions. Generality of Rapoport's rule is still unclear (Grau et al. 2007; Rohde et al. 1993; Rohde 1996), a study by Zhou et al. (2019) found Rapoport's rule to be contradictory across various species from the same region.

Numerous hypotheses have been put forward for describing altitudinal variation in the range size oforganisms, of them climatic variability is the most highlighted (Gaston, 2003; Stevens, 1989). For example, Sunday et al. (2011) demonstrated that in terrestrial ectotherms, both climatic variability and the range of thermal tolerance increase significantly with latitude.Similar to this we advocate that pyraloid species occurring at higher latitudes must have the physical capability to withstand extensive temperature extremes allowing them to encompass such wider distributional ranges. Additionally, lepidopteranspecies range size can also be influenced by existence, diversity and abundance of host/nectar plants.

Species having limited range size may experience higher extinction rates during glacial periods and due to climatic fluctuations more generally (Brown, 1995; Dynesius & Jansson, 2000), is the another possible explanation for our results. The east–west alignment of the Himalayan mountain ranges creates significant geographic barriers, especially for the species with narrow altitudinal ranges, restricted thermal tolerance, and limited dispersal capacity. During cooling periods, these species likely faced increased extinction risk, as the geographical barriers prevented their movement into potential glacial refugia (Habel et al., 2010). Over the time, this may have favouredthe species with broader distribution ranges at higher latitudes (Brown, 1995). In Europe, Seifert et al. (2022) pointed out similar phenomenon for Geometrid moths.

CONCLUSIONS

The present study aimed at revealing the patterns of Pyraloidea diversity (richness, turnover and species range size) showed a hump shaped species richness pattern with highest value at mid elevation (1500 m) and the turnover value showed its lowest value at the same elevation while species range size increased with increasing elevation. All of these point towards the fact that pyraloid species move frequently between mid-elevational and high elevational locations giving them greater range size at higher altitudes and exerbating richness and lowering turnover rates at mid-altitudes. Our results show that there is difference in altitudinal preference at lower taxonomic level (subfamily) for both families. Thus for detecting fine scale changes lower taxonomic units must be preferred. Moreover, difference in the study design also makes it difficult to compare the results across studies.Additionally, different taxa may respond to different niche axes, which have shown association in turnover–richness components. Thus, future studies should consider examining factors like, productivity, net area, physiological traits, speciation history etc. in order to better understand the processes and factors shaping Pyraloidea diversity and distribution along elevational gradients in the Eastern Himalayas. Speciation in the Himalayas is expected to be linked to the Himalayan uplift and subsequent climatic changes that followed but still the process of speciation that gave rise to rich and unique biodiversity within the Himalayas is not yet fully understood, likely due to sampling difficulty of Himalayan species (Xu et al., 2021).

Understanding the potential mechanism behind this phenomenon could provide key insight into the patterns of diversity and distribution of moths in the region. Since a variety of factors and complex interactions are known to play role in shaping species ranges, including physiological traits, history of speciation and dispersal, and continental shape constraints (Webb & Gaston 2003). To our knowledge, this will be the first kind of effort to study Pyraloidea diversity along elevational gradient in the Himalayas. Its outcome will provide baseline information for future studies regarding documentation of the diversity, formulating conservation plans, and studied related to climate change, especially in the eastern Himalayan region which is the meeting point of three global biogeographic zones and also part of the Himalayan biodiversity hotspot.

Declarations

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution

Avishek Talukdar- Writing original draft, Specimen identification, Conceptualisation, Statistical analysis; Navneet Singh- Reviewing, validation, Supervision.

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Figures

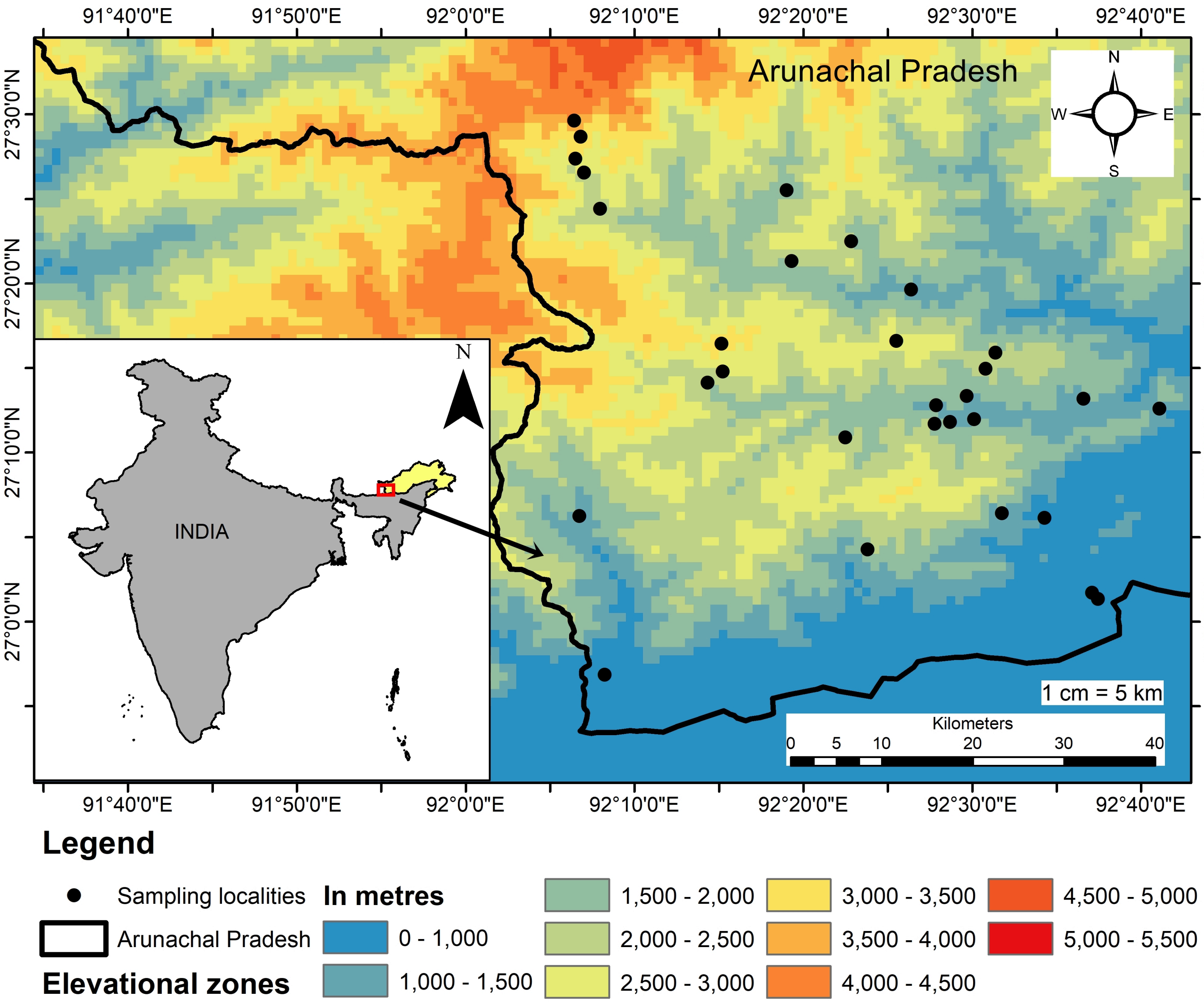

Figure 1

Figure showing the study area and the sampling points

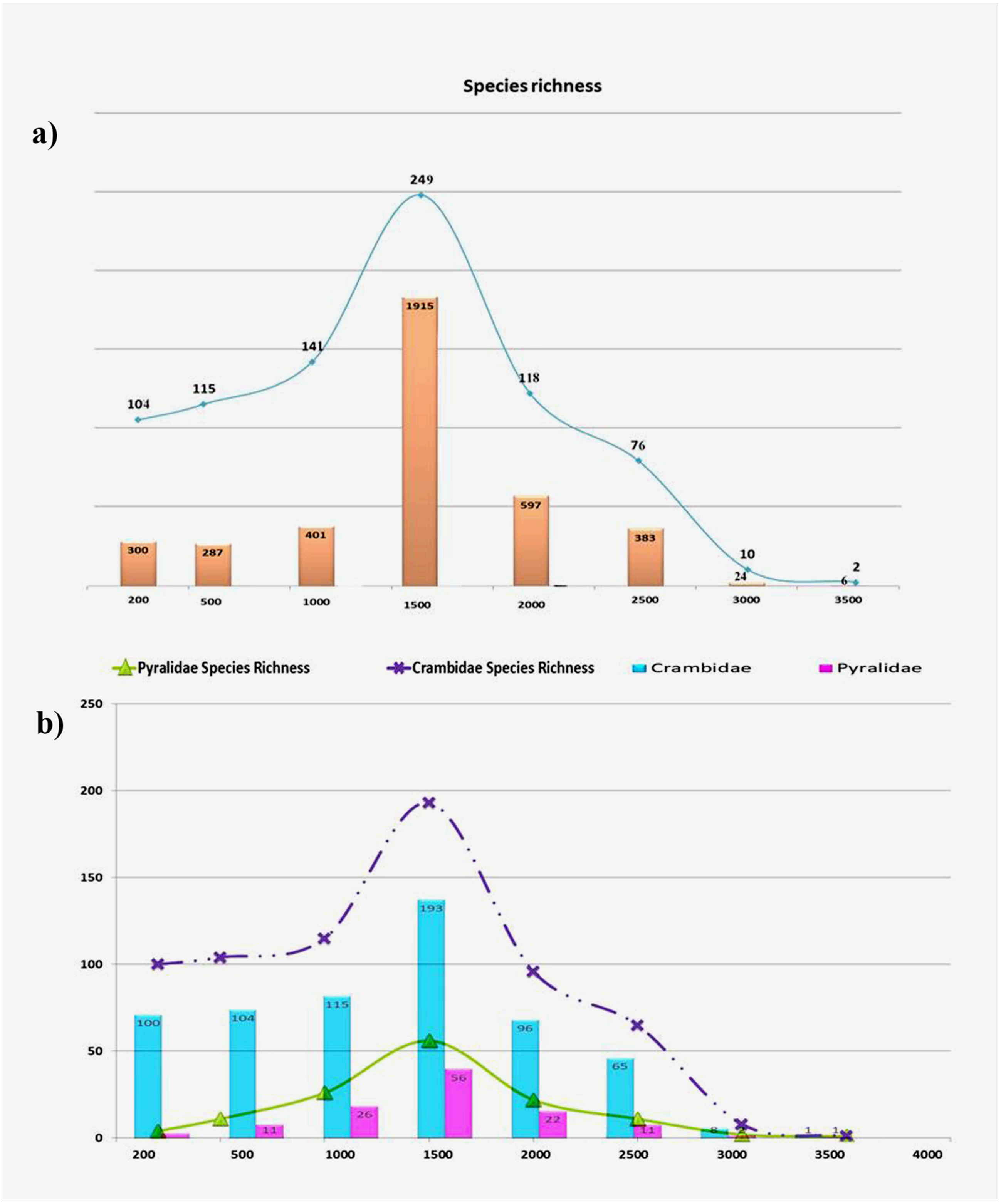

Figure 2

species richness and abundance variation along elevation in a) Pyraloidea, b) Pyralidae and Crambidae.

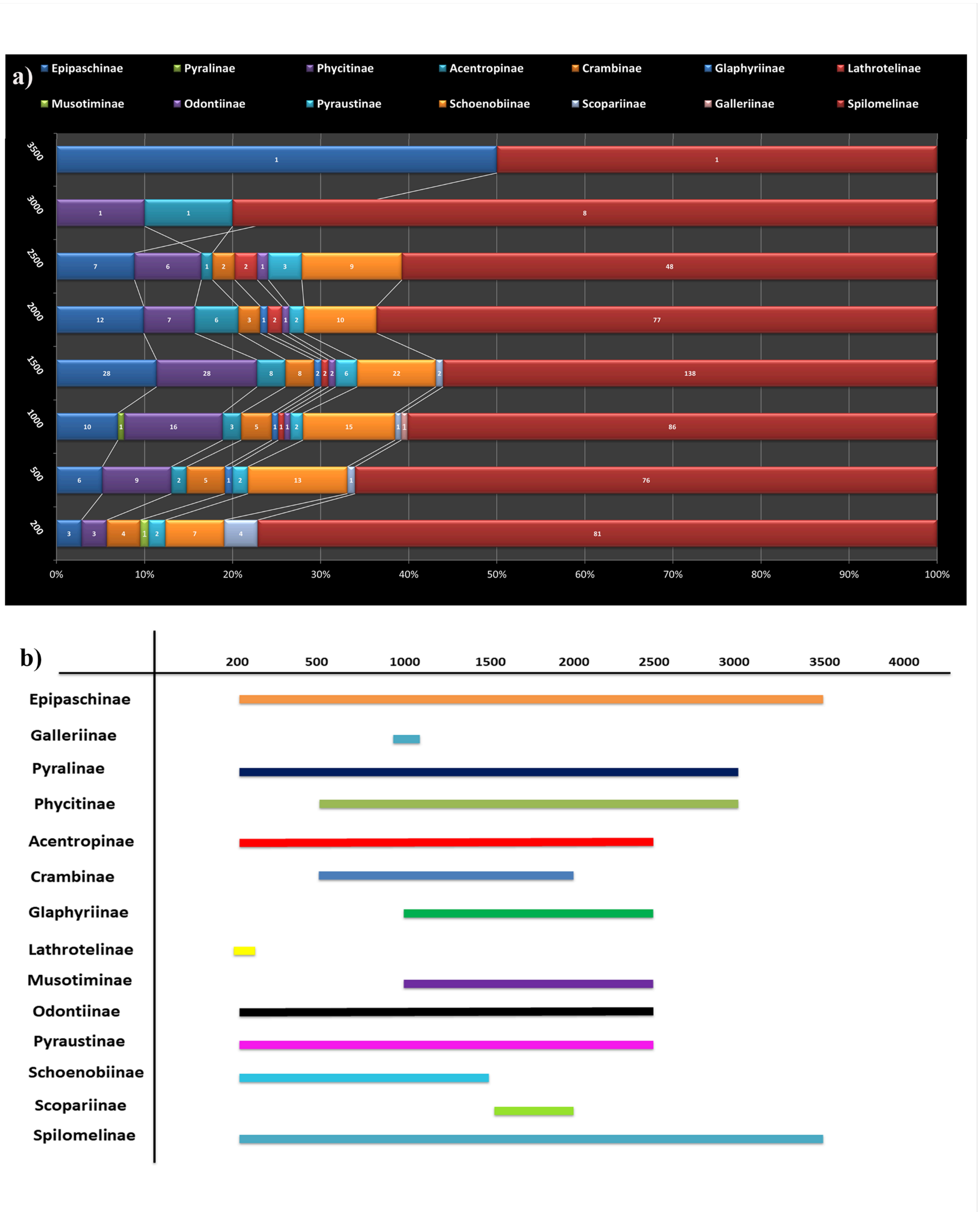

Figure 3

taxonomic composition of sub-families and their altitudinal distributions along elevational gradient

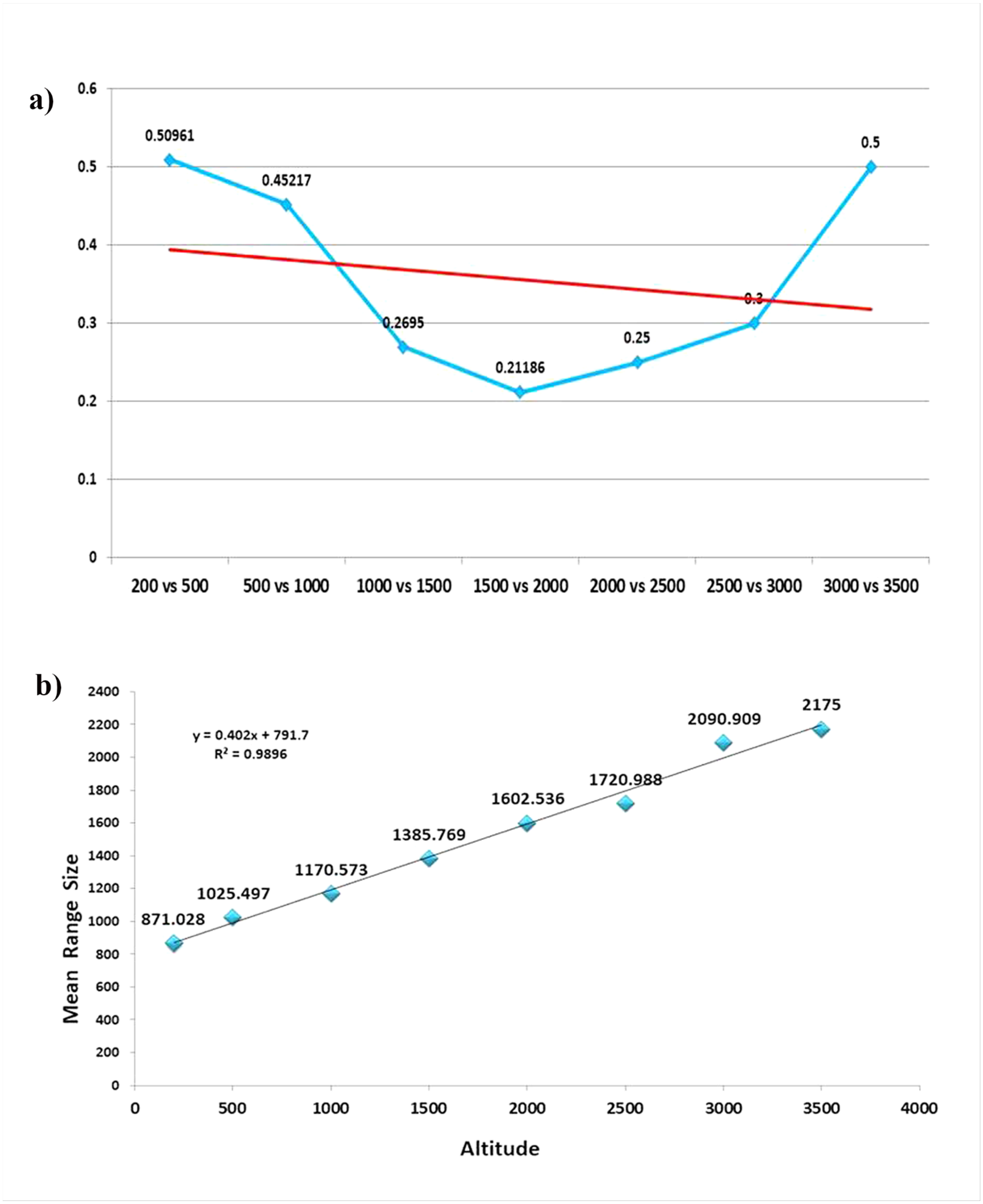

Figure 4

Variation in a) Turnover and b) species range size of Pyraoidea along elevation

Supplementary Files

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- Supplimentaryfile1speciesrangesize.docx
- Supplimentaryfile2speciesturnover.xlsx
- Supplimentaryfile3samplingcompleteness.docx
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- Supplimentaryfile5altitudinalrichness.xlsx