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envis
wildlife and protected areas

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

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ARTHROPODS AND THEIR CONSERVATION IN INDIA (INSECTS & SPIDERS)

envis
Wildlife and protected areas

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Establish a data bank on information related to wildlife and wildlife protected areas, and thereby build up a repository and dissemination centre for information on wildlife science;

Promote national and international cooperation, and exchange of wildlife related information;

Provide decision makers at the apex level with information related to conservation and development.

ENVIS BULLETIN

Wildlife and Protected Areas

Project Leader
P. R. Sinha

Project Coordinator
V. B. Mathur

Project Co-coordinator
S. A. Hussain

Senior Research Fellow
Shazia Quasin (Feb 2012 - Feb 2013)
Anant Pande (April 2013- onwards)

Project Assistant
Jyoti Prasad Nautiyal

Advisory Committee
P. K. Mathur
B. C. Choudhury
K. Sivakumar
Y. S. Verma
R. Thapa
K. K. Shrivastva
Dinesh S. Punder

Wildlife Institute of India
Chandrabani, Dehradun-248001, India
Tel.: +91 135 2640111-115, Fax.: +91 135 2640117
Email.: wii@envis.nic.in, envis@wii.gov.in

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Abesh Sanyal & V.P. Uniyal

EDITORIAL PROECESSING

Jyoti Prasad Nautiyal & Rajeev Thapa

PROOF EDITOR

Mr. Kumaran Sathasivam,
Palladium Documentation, C - 14,
Casa Granda, 13 & 14 Ellai Amman Koil Street,
Chennai, Tamil Nadu - 600020

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Wildlife and protected areas

Arthropods and their Conservation in India (Insects & Spiders)

EDITORS

V.P. Uniyal

Aseem Shrivastava

SENIOR RESEARCH FELLOW

Shazia Quasin (Feb 2012 - Feb 2013)

Anant Pande (April 2013- onwards)

PROJECT ASSISTANT

Jyoti Prasad Nautiyal

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Editor's Note

Having existed for more than 400 million years after surviving the Permian and Cretaceous mass extinction, arthropods have been the most successful group of all living beings and along with other invertebrates constitute more than three-fourth of today's global biodiversity. Despite such richness of species and their role in all ecosystems, much of the world beyond taxonomists and entomologists does not realize the benefits accrued from conserving arthropods. Much of the perception of human kind beyond this academic horizon about the arthropods is only as pest or as some harmful elements. The current global conservation attention is primarily on charismatic mega-vertebrate fauna, the invertebrate/arthropod conservation has yet to fully join the mainstream of global biodiversity conservation efforts and in words of R. Dunn, arthropod conservation always remains the awkward "*kid sister of vertebrate conservation*."

Numerous recent developments taking place worldwide in taxonomy, inventorying, monitoring, data compilation, statistical analysis and science communication are facilitating in overcoming these impediments to plan effective *in-situ* conservation and in both policy and practice. In India, there are still enormous opportunities for original research in this particular subject to generate baseline data which are crucial for conservation planning of arthropods. In view of this, the Wildlife Institute of India, decided to come up with an issue of ENVIS Bulletin titled "Arthropod and their conservation in India (Insects & Spiders)" with the hope to provide a snapshot of current research trends and future needs in this particular aspect of biodiversity conservation. We have solicited papers from eminent scholars to cover all possible facts and facets of arthropod conservation especially on issues and challenges. Special emphasis has been on the state of our current knowledge of diversity of insects and spiders *viz*. challenges for taxonomy in Indian context and review of Indian lepidoptera; diversity and attributes of spiders in human-dominated landscape and overview of Mygalomorph diversity of India.

This issue of ENVIS includes a review on important order of insects *i.e*. Lepidoptera by having papers on rarity of oak forest butterflies, patterns in species composition and abundance of high altitude butterfly fauna and diversity and indicator species of moths in different vegetation zones. We have also included a paper on the role of butterfly garden in promoting biodiversity conservation and role of entomology outreach education in developing insect interest groups in India.

Overall, we have covered all the important issues on arthropod conservation in Indian scenario. We thank all the authors and reviewers who kindly agreed to contribute to this issue and collectively bring their vast knowledge and expertise to generate more information on status, biology of arthropods and deliver them to policy/decision makers and stakeholders for effective conservation. The document could be of immense use as reference for the information needed in conservation planning.

We would like to request for your feedback on the contents and quality of this issue.

This voluminous and important information on poorly known taxa as lower invertebrate could motivate many more researchers in this field.

V.P. Uniyal
Aseem Shrivastava

HIGHER-TAXA SURROGACY AND EFFICIENCY IN SPIDER CONSERVATION: A CASE STUDY FROM TERAI CONSERVATION AREA, INDIA

***Upamanyu Hore*[1] *and V.P. Uniyal*[2]**

1. *Amity School of Natural Resources and Sustainable Development, Amity University, Noida, Uttar Pradesh.*
   email : uhore@amity.edu / upmanyu.hore@gmail.com
2. *Wildlife Institute of India, Chandrabani, Dehradun.*
   email : uniyalvp@wii.gov.in

ABSTRACT

The establishment of a strong relationship between species richness and a surrogate index is a critical issue in conservation biology. Such a relationship could provide the basis for the establishment of cost-effective and easy-to-monitor methods for measuring biodiversity, providing an alternative for prioritization of sites for conservation. Both family and genus richness are tested for their ability to predict the number of spider (Araneae) species independent of sampling detection, spatial autocorrelation, area, geographical location and type of habitat. Data from two protected areas of Terai Conservation Area (TCA) were used as a test case. Genus richness is considered to be a good surrogate of species richness, despite some caution being needed regarding comparison of sites with considerably different sampling effort. Genus alone is found to be reliable indicator for ranking sites according to taxa richness or for determining near-minimum sets of sites for conservation. This study recommends surrogacy at this higher taxonomic level as a promising approach for prediction of spider species richness or evaluation and ranking of areas according to conservation importance.

INTRODUCTION

Biodiversity on Earth is rapidly diminishing, and conservation biologists are struggling to catalogue and preserve what remains of it. The rapid decline in biodiversity and practical challenges in describing and enumerating it rigorously enough, including the money, effort, expertise and time involved (May, 1994), have urged conservation biologists to rely on surrogates for explaining patterns in biodiversity. Such approaches try to overcome the problem of the enormous amount of resources (*e.g*. time, money, taxonomists) required to reach close-to-complete inventories, if at all such a goal is possible to achieve. Among the most popular of these approaches is the use of higher-taxa surrogates, as proposed by Gaston and Williams (1993; see also Williams, 1993; Williams and Gaston, 1994). Others include the use of indicator (or surrogate) groups of overall richness *(e.g.* Pearson and Cassola, 1992; Beccaloni and Gaston, 1995; Prendergast and Eversham, 1997) and the inference of diversity from available information on environmental variables (*e.g.* Braithwaite *et al.*, 1989; MacNally *et al.*, 2003). Despite all the pros and cons that these have, the higher-taxon approach has several advantages, allowing information to be obtained on a large number of taxa with relatively little effort and use of resources. Another crucial advantage is the retention of broad biological information, which allows distribution patterns to be understood (Eggleton *et al*., 1994; Williams *et al*., 1994; Gaston *et al*., 1995) and conservation priority areas to be defined more efficiently (Williams, 1993; Williams *et al.*, 1994; Vanderklift *et al*., 1998), which is, after all, the ultimate goal of conservation biology. The higher-taxon approach has been used at both local and regional scales (Gaston *et al*., 1995; Larsen and Rahbek, 2005), and use of this approach could be highly demanding in terms of performing direct species measurements. Although most previous work points to reliability in the use of higher-taxa surrogacy in many different kinds of organisms (Williams and Gaston, 1994; Williams et al., 1994; Gaston and Blackburn, 1995; Vanderklift *et al*., 1998; Balmford *et al*., 2000), caution should be exercised when applying the method and interpreting results since the method is subject to a series of limitations such as sampling effort, data quality, habitat type, geographic location and spatial autocorrelation (Gaston and Williams, 1993; Andersen, 1995; Grelle, 2002; Cardoso et al., 2004).

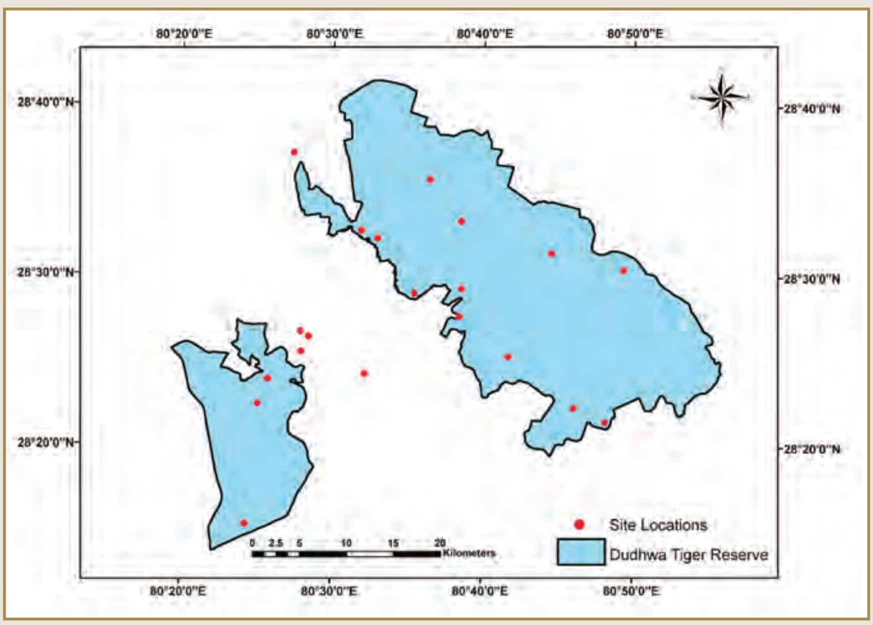
Nearly all studies of higher-taxa surrogates have simply looked at the extent of correspondence between the richness of areas measured at different taxonomic levels. But efficient reserve networks consist not just of rich sites but of sites that are rather different from one another biotically and that, therefore, exhibit high between-site complementarity (Pressey and Nicholls, 1989; Pressey *et al.*, 1993; Williams, 1998). Hence a full evaluation of the utility of the higher-taxon approach for reserve planning should include a consideration of the degree of cross-level correspondence in patterns of complementarity as well as richness and an assessment of how well entire reserve networks designed using information on genera or families manage to capture species-level diversity (Vane-Wright and Rahardja, 1993; Williams, 1993; Balmford *et al*., 1996a). One critical limitation is that even those tests that have addressed these other concerns have nearly always targeted relatively species-poor groups such as birds and mammals (Balmford *et al.*, 1996a). This is not surprising as very few good-quality, local-scale data sets of highly speciose groups such as insects and arachnids currently exist. Nevertheless, rapid assessment methods are obviously most needed for megadiverse groups, for which a shortage of expertise is compounded by the long time required to sort records down to the level of species (Bloemers *et al*., 1997; Lawton *et al*., 1998).

With this work, we intend to provide evidence of the possible usefulness of the higher-taxa surrogacy approach with spiders in the Terai, testing it as a species richness predictor. We also consider the effects of environmental and methodological factors on the validity of predictions. Finally, we test the use of this kind of surrogacy as a tool for reliable definition of conservation priority sites, either by ranking them according to taxa richness or by considering the complementarity of known taxa between sites to examine how well subsets of our sites capture species-level diversity when using information on species, genera, families and orders. The species richness of spiders and their respective spatial distributions are virtually unknown in India, with a certainly very low figure of 1520 species registered for the country (Sebastian and Peter, 2009). Although not even higher-taxa data are available for most of the country's territory, given the difficulty in identification of species, many remaining to be described or discovered, it seems advisable to test for future use such potential tools as different surrogates of biodiversity.

METHODS

Fieldwork design was implemented to test for several effects that can influence the higher-taxa surrogates approach—geographical location, type of habitat and sampling effort. Two protected areas of the Terai Conservation Area (TCA) under the jurisdiction of Dudhwa Tiger Reserve, one in the north—Dudhwa National Park—and the other in a nearby area in the south—Kishanpur Wildlife Sanctuary were sampled in 2006–2007 (Fig. 1).

Figure 1.



Map showing sampling sites in TCA

For simplicity, these two areas are simply referred to hitherto as belonging to northern and southern geographical regions. Ideally, all sites in all protected areas were sampled during the same year. We chose such areas because of their high habitat diversity. By comparing the two regions, the geographical effects on the surrogacy methods could be tested. In each area, we sampled several sites, a total of 10, trying to cover a majority of the most significant habitats represented. This way, we also considered the habitat effect by differentiating sites with arboreal cover from those without and those with "natural" vegetation from the ones dominated by introduced vegetation or under severe human influence or management. Ten major vegetation types were identified, and two sampling sites per vegetation type were selected for spider sampling. The size of the sampled sites ranged from 1.8 to 13.3 km^2. Spiders were sampled along 50 m transects using pitfall traps and semi-quantitative sampling. Ten transects were placed randomly within each vegetation type. Pitfall sampling was carried out for 64 weeks, and other semi-quantitative sampling methods were used on 64 occasions (once every week) at the same sampling sites. The pitfall traps consisted of cylindrical plastic bottles of diameter 10 cm and depth 11 cm (Churchill and Arthur, 1999). Six pitfall traps were laid along each transect line at intervals of 10 m. Traps were filled with preservative (69% water, 30% ethyl acetate, and 1% detergent). After seven days, the specimens were removed from the traps. This allowed us to maintain the spider specimens in a good condition before they were processed in the laboratory and identified. Semi-quantitative sampling involves aerial sampling; ground collection; beating; litter sampling; or sweep netting. Each sampling method involved 1 hour of active sampling, measured using a stopwatch.

ANALYSIS

To test if either family or genus richness can be reliably used to predict species richness, regression analysis was performed over all the available data. Linear, log-log and exponential regression were tested. We used both the percentage of variance explained by the independent variable and visual evaluation of the scatter plots as measures of adjustment, surrogacy reliability and predictive power. Searching for the possible influence of sampling detection, geographical location and habitat type on the surrogacy results, we also adjusted regression lines after separating the sites according to their characteristics, one factor at a time. Analysis of covariance (ANCOVA) was carried out to test for statistically significant differences between regression lines. If differences were found, the factor involved was considered to potentially influence the reliability of surrogacy. The SPSS 16.0 software package was used for statistical analysis. We estimated the relationship between study site areas. In order to test if the study site area affected the relationship between species richness and higher-order richness, we regressed the residuals of the relationship with the site area. The pattern of diversity is known to be spatially autocorrelated (Lennon *et al*., 2001). Autocorrelation distorts systematically the classical tests of association and can generate misleading results—correlation coefficients, regression slopes and the associated significance tests (Clifford *et al*., 1989; Lennon *et al*., 2001). To avoid this, we applied the modified correlation test of Clifford *et al.* (1989), which corrects the significance of the Pearson correlation coefficient for the spatial dependency within and between the two patterns examined. This correction uses the concept of "effective sample size". This is the equivalent sample size for the two patterns when the redundancy produced by spatial autocorrelation is removed. In the present study, the effective sampling size was always equal to or close to the real sample size, and thus the spatial autocorrelation did not affect the estimated level of statistical significance.

Two approaches were tested for prioritisation and ranking of sites for conservation. The first approach is scoring approach, which uses the raw number of taxa represented in each site as the sole value for ranking sites (Table 1). The Spearman rank correlation index was used to test for surrogacy reliability in the scoring of sites. In addition, scatter plots of family and genus richness versus species richness ranking of sites were used for visual inspection of reliability. The second approach we tested a more efficient iterative approach of conservation priority ranking. For each of the considered taxonomic levels (family, genus and species), we first choose the site with the highest species richness and then calculate the complementarity richness by counting the species that are not already present. Subsequently we choose a site with the highest complementarity and repeat the procedure until all the species are represented in the data matrix. Finally we reorder the sites by complementarity richness and chose the richest site (combining the value of species richness and complementarity) and from it, in a stepwise manner, the one site that would further raise the number of represented taxa was added to the set of sites to be considered for protection. In case of ties, we chose the most species rich site in the respective taxa. By doing so, we tested the effect of using higher taxa for choosing a near-minimum set of sites that potentially preserves the maximum number of species.

RESULTS

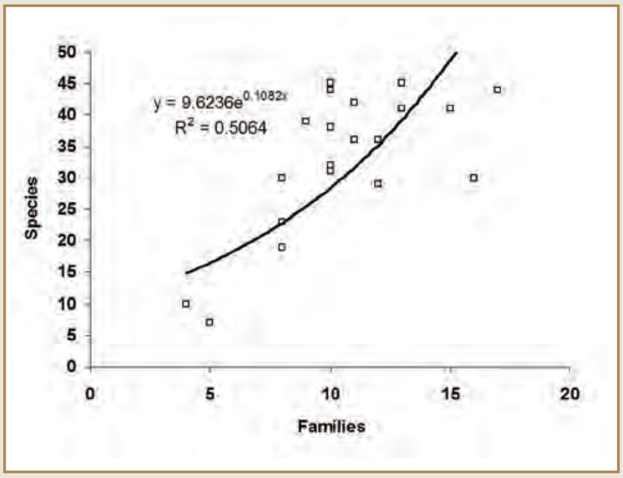
A total of 186 species belongs to 77 genera and 27 families were collected during the entire sampling period. Of these, 67 species (36% of all species) belong to morphospecies. The Terai spider assemblage represents 20% of all genera described from India, which is very rich. The nomenclature adopted consistently follows Platnick's (2008) world spider catalogue.

SPECIES RICHNESS PREDICTION

CHOOSING THE BEST SURROGATE

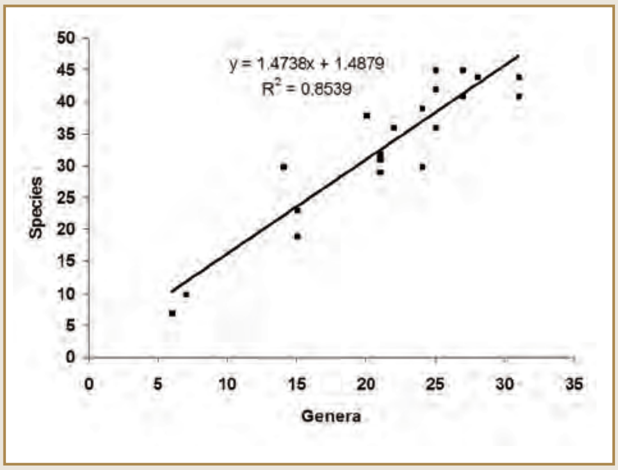
After fitting all previously defined regression types—linear, log-log and exponential—to family and genus taxonomic levels, we chose the ones with the highest regression coefficient value. A non-linear exponential relationship was found for the families and a linear relationship for the genera (Fig. 2). Both taxonomic levels present a highly significant relationship with the number of species ($n = 20$, $p < 0.001$); however, the genus richness seems to have a much better predictive power, with a high r^2 value.

Figure 2 a.



(a) Exponential relationship between family and species richness;

Figure 2 b.



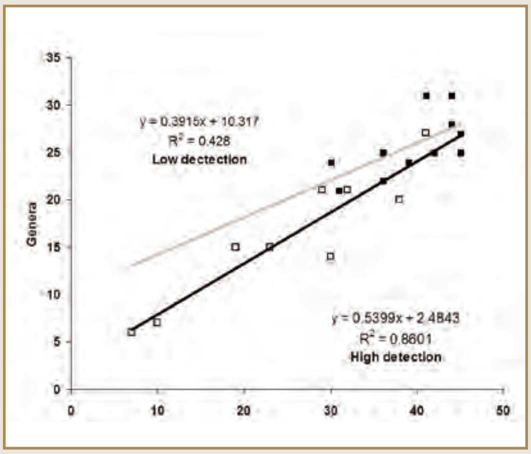
(b) linear relationship between genus and species richness in all 20 sites sampled for spiders in the study area

INFLUENCE OF FACTORS

Since genus richness was found to have high predictive power and has a linear relationship with species richness, in subsequent tests for influence of factors on taxonomic level, only genus-level data were considered. Comparing the regression lines of sites representing different detection (captured ratio for individuals per species) level for individual species was found significantly different ($n = 20$, $p < 0.05$) (Fig. 3a). This was to be expected as the heterogeneity in the detection probabilities of different species capture varies with local and regional species pools. The same did not happen with other factors, whose differences were not found to be statistically different.

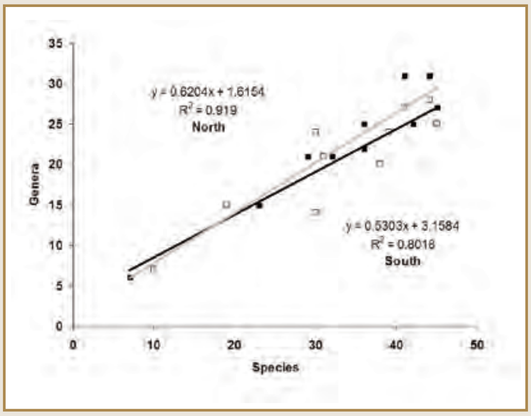
Regression-based analysis demonstrated only a weak correlation between area and different taxonomic levels for all classes (r2 = 0.123 and 0.204, respectively). The correlation between area and the residuals of the relationship between species richness and higher-taxonomic-level richness was not significant ($a = 0.001$).The spatial autocorrelation among sites seems to be not a significant effect since the effective sample size deviated only slightly from the real sample size without altering the results.

Figure 3 a.



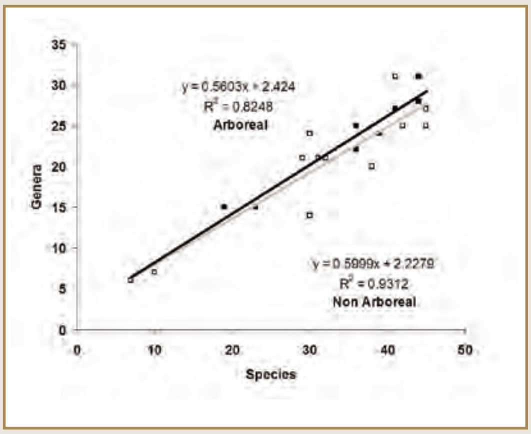
(a) Comparison of the relationship between genus richness and species richness between sites with high (open squares) and low (filled squares) detection;

Figure 3 b.



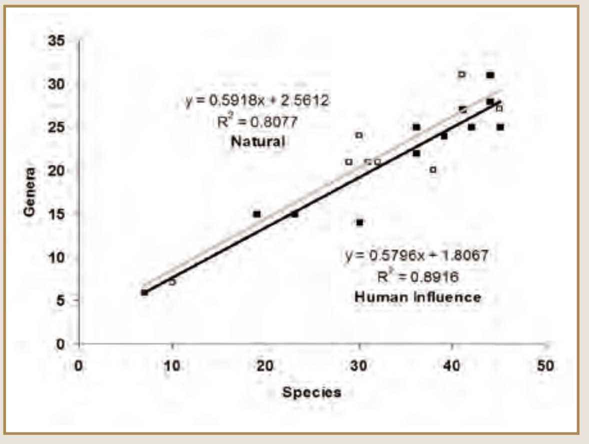
(b) comparison of sites in the northern (filled squares) and southern (open squares) regions;

Figure 3 c.



(c) comparison of sites with (filled squares) and without (open squares) arboreal cover;

Figure 3 d.

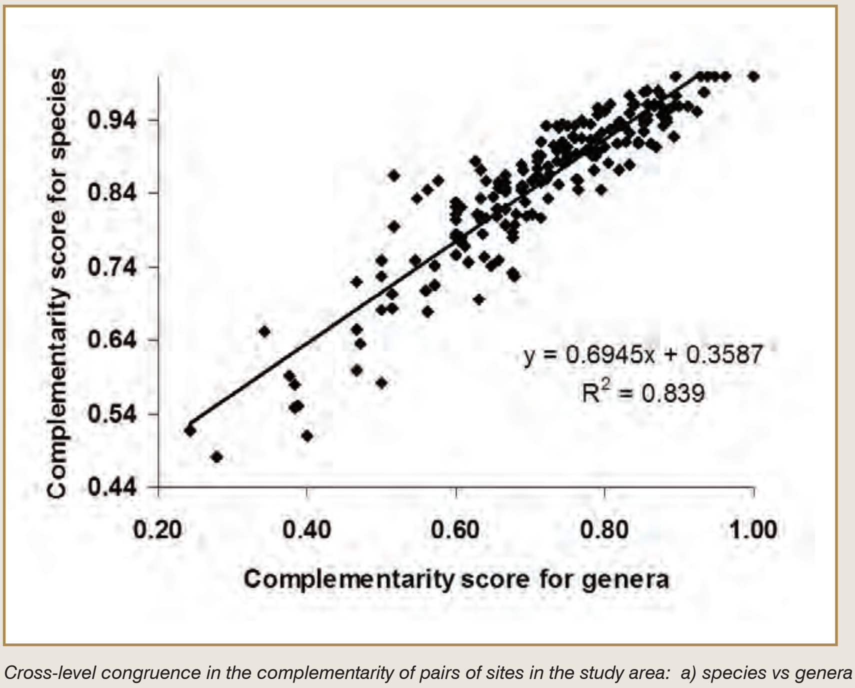


(d) comparison of "natural" areas (open squares) and those under intense human influence (filled squares).

CROSS-LEVEL CORRELATIONS IN COMPLEMENTARITY

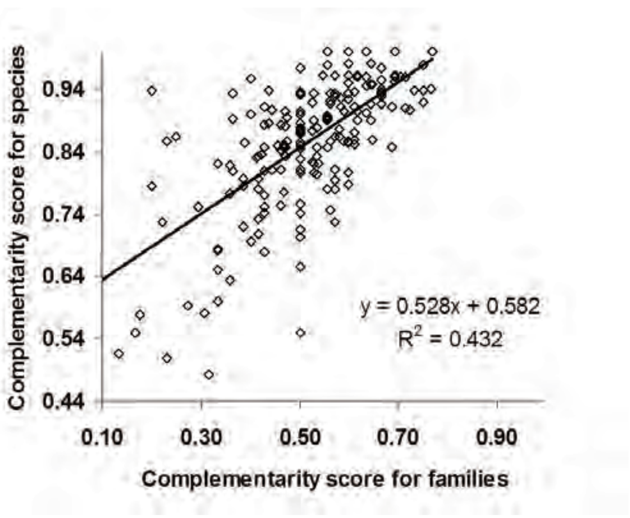
There was good congruence in the complementarity patterns measured in terms of species and genera but not across families (Fig. 4b). The between-site complementarity of species was quite closely related to the between-site complementarity of genera (r^2 = 0.84, n = 0 pairs of sites, $p < 0.001$); thus sites with very different spider species also had very different spider genera, and vice versa. However, the species-level complementarity could be far less closely predicted compared with the family-level complementarity (for species vs families, r^2 = 0.44, n = 20, $p < 0.10$). These results were apparently not confounded by variations in the difference in area of paired sites (since pairs are of widely differing size).Thus, it appears that the match in how well sites complement each other when assessed in terms of species and genera is real and, alongside congruence in richness, explains why sets of sites identified using spider genera do so well at representing spider species.

Figure 4 a.



Cross-level congruence in the complementarity of pairs of sites in the study area: a) species vs genera

Figure 4 b



(b) species vs families. Complementarity scores are calculated as the number of species or genera or families found at just one or the other site, divided by the combined total found at either or both (Colwell and Coddington, 1994).

Cross-level congruence in the complementarity of pairs of sites in the study area:

CONSERVATION PRIORITY

Scoring Approach

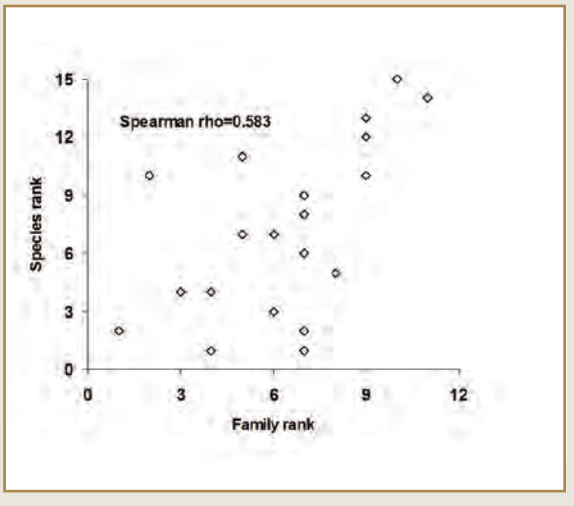
Using the rank of sites according to their taxa richness, families were found to have a low predictive power of species-based site ranking (Table 1), despite the high Spearman rank correlation value of 0.855. Examination of the rank scatter plot (Fig. 5b) also leads to conclusions about the low reliability of the family surrogacy approach. Genera, in contrast, seem to rank sites in much the same way as species do (Table 1) (Spearman rank correlation = 0.962). Predictive power is especially high at the highest and lowest ranked sites, not being as good at the middle ones (Fig. 5b).

Table 1. Taxa richness of sampled sites and respective ranking

Site	Richness			Rank		
	Species	Genera	Families	Species	Genera	Families
grsk2	45	27	13	1	3	4
pssk1	45	25	10	1	4	7
grsd2	44	31	17	2	1	1
rpsd2	44	28	10	2	2	7
pssd2	42	25	11	3	4	6
grsk1	41	31	15	4	1	3
mssd2	41	27	13	4	3	4
rpsk1	39	24	9	5	5	8
rpsd1	36	22	12	7	6	5

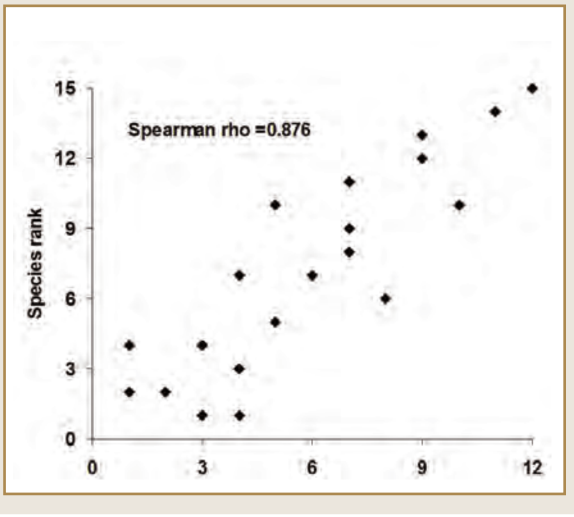
rpsk2	36	25	11	7	4	6
mssk1	32	21	10	8	7	7
pssd1	31	21	10	9	7	7
grsd1	30	24	16	10	5	2
mssd1	30	14	8	10	10	9
mssk2	29	21	12	11	7	5
plsd2	23	15	8	12	9	9
plsk1	19	15	8	13	9	9
plsk2	10	7	4	14	11	11
plsd1	7	6	5	15	12	10

Figure 5 a.



(a) Comparison of site ranking according to family and species richness;

Figure 5 b.

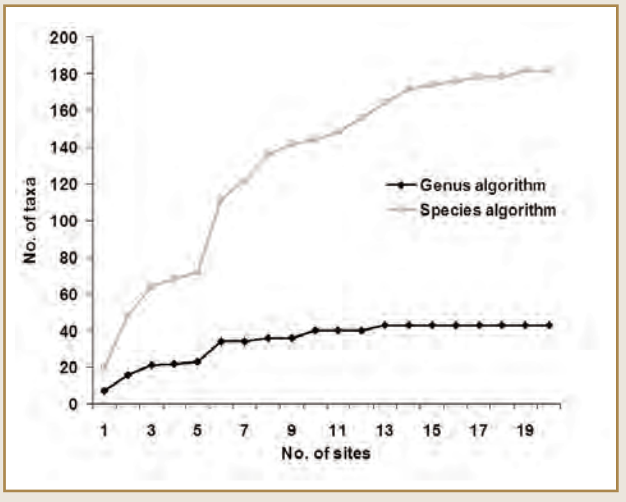


(b) comparison of site ranking according to genus and species richness

ITERATIVE APPROACH

Although a scoring approach to site ranking can be evaluated for future use, it is not the most efficient method for establishing conservation networks of sites. Complementarity is a fundamental issue to be taken into account. Thus, scoring of sites was not done simply according to their richness values but according to which ones will protect the maximum number of species not included in previously chosen sites. By using accumulation curves, the effects of adopting this approach for the different taxonomic levels can be carefully considered. The objective is to check what proportion of species can be protected by using the same number of sites that protects all considered higher taxa. Genus-level data were chosen for this analysis since it fitted best with the species algorithm. The number of sites (13 sites; 65% of all sites sampled) necessary to include all genera is enough to protect, at most, 90% of the species (Fig. 6).

Figure 6.



Accumulation curves of the number of taxa represented by adding sites in a stepwise manner, considering the complementarity algorithm

DISCUSSION

The results of the study suggest that only genus richness can be used as a significant and reliable surrogate of species richness, with a much higher regression coefficient value and predictive power compared with families. Its linear relationship is also simpler than the more complex, non-linear, exponential relationship that family richness has with species richness. Previous studies also recognize the same strong relationships between species and genera richness, while several studies highlight caveats on the use of family richness (Williams and Gaston, 1994; Gaston and Blackburn, 1995; Balmford *et al.*, 1996a, 1996b; Roy *et al.*, 1996; Grelle, 2002; Cardoso *et al*., 2004; Bergamini *et al.*, 2005). However, there is evidence demonstrating family richness to be an equally good predictor of species richness (Williams *et al*., 1994; Negi and Gadgil, 2002; Báldi, 2003). Given the findings of strong correlation and predictive power between higher-taxonomic-level richness and species richness, this study concluded that genus-level richness could be used in describing patterns of species diversity. However, caution should be exercised regarding the decision on the taxonomic level to be used in a similar analysis, which should be based on a preliminary analysis undertaken at the region of interest. This is mainly because the responses of organisms to environmental variability differ for the same group of species from region to region.

Species richness is known to increase as the sampling area and environmental variability (here measured as habitat diversity) increase. In the present study, the relationship between species richness and area or habitat diversity was found to be generally weak. Neither geographical location nor area nor habitat was found to have significant influence over the usefulness of higher-taxa surrogacy at the genus level. When the sampling effort is the same, the only factor found that may limit the use of higher-taxa surrogacy is imperfect detection of species in single or multiple sites.

Because species are detected imperfectly, some species that were not detected at the site may have in fact been present (*i.e.*, a false absence), while others could be genuinely absent from the site (*i.e.*, not part of the local community during that sampling period). Repeated surveys are needed to estimate the detection probability, and the assumptions that need to be fulfilled are (1) the occupancy status of the site for each species does not change during the season and (2) changes occur completely at random (*i.e.*, the members of the local species pool present at the site are constant during the sampling period) (MacKenzie *et al*., 2006).

The results also show that fine-scale variations in genus-level richness mirror variations in the species richness. This is also due to moderate cross-level correspondence in the extent to which different sites complement one another: sites that are highly complementary at the species level also tend to exhibit high complementarity at the genus level, and *vice versa*. In contrast, data on families and orders are much poorer predictors of patterns of species richness and species-level complementarity.

Attempts have been made recently to explore the performance of the higher-taxa approach in identifying priority areas for conservation (Balmford *et al.*, 2000; Fjeldså, 2002; Whiting *et al*., 2000). Accordingly, some encouraging results have been obtained, at a continental scale, but only for large grain sizes (Larsen and Rahbek, 2005). Such an analysis was performed at the regional scale in order to explore the ability of different taxonomic levels to encompass species diversity. The aim was to investigate the efficiency of different levels of information in prioritizing sites for conservation and to investigate the reliability of the higher-taxon approach. Analysis demonstrated that the higher-taxon approach performed as well as the species-level approach. Yet, its use in reserve selection should follow further analysis.

Genera, but not families, are also considered a good surrogate for choosing priority sites for conservation. Whether we choose to apply a simple scoring approach or a much more efficient iterative algorithm approach to the problem of sites ranking, genera can be used as a surrogate of species when no taxonomic data are available on these. The use of caution is suggested, and in case of doubt, a conservative approach should be taken, by trying to protect more sites than those expected to be necessary to represent all genera. This will guarantee that the proposed reserve network covers a large proportion of the species.

From a practical point of view, the method could be applied to monitoring and management proposes to frequently study and determine changes in biodiversity richness and distribution. The results show clearly that the higher-taxon approach could be used for performing rapid area inventories. Assuming, very conservatively, that there are no savings from higher-taxon surveys in terms of field time, that subsequent identification of spiders in the laboratory takes no longer than fieldwork, and that the identification time required for genera is fully half that for species, it follows that genus-level surveys will take at the most only 50% of the time required for sorting down to species. Perhaps more important than time savings, in most situations (e.g. the highly diverse tropics), the great majority of the work required for genus-level inventories of spiders could be carried out by well-trained parataxonomists or by nonspecialists using local or regionally based operational keys, rather than by expert scientists (Oliver and Beattie, 1996; Krell, 2004). Apart from spiders, the higher-taxon approach should continue to be encouraged for other, richer arthropod groups, and the cautious use of genus- level surveys represents a very promising route to setting priorities for megadiverse groups on the conservation map. The efficiency of the method to be used for prioritization of conservation areas needs to be demonstrated for different groups of taxa in different biomes and in different biogeographical areas (Balmford *et al*., 2000).

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SPIDER DIVERSITY ATTRIBUTES IN A CULTURAL LANDSCAPE DOMINATED BY FIELD CROPS AND FRUIT ORCHARDS IN THE KONKAN REGION OF MAHARASHTRA

Nilam Vasant Bhuvad, Vinayak Krishna Patil, Sanjay Ghanshyam Bhave, Satish Sopan Narkhede, Vinayak N. Jalgaonkar and Vinod Manikrao Mhaiske

College of Forestry, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, District Ratnagiri, Maharashtra – 415 712.
email: vinjack@sify.com

ABSTRACT

A study was undertaken to explore the spider diversity of important agro-ecosystems (rice, finger millet, cashew and mango) in the Konkan region of Maharashtra. Standard-time visual sampling was done with spatial and temporal replication from June 2010 to March 2011. A total of 4035 individual spiders were recorded. They belonged to 141 species, 70 genera and 21 families. The families Araneidae and Salticidae were the dominant families overall. A total of 29, 35, 69 and 98 species were recorded in rice, finger millet, cashew and mango, respectively. The completeness of the surveys was found to be as high as 87% in mango and as low as 49% in finger millet on the basis of proven reliable estimators of species richness. Simpson's index of dominance showed a mango (0.119) > rice (0.103) > finger millet (0.081) > cashew (0.054) trend. On the other hand, the Shannon diversity index showed a cashew (3.41) > mango (3.02) > finger millet (2.81) > rice (2.73) trend. Beta diversity indices for combinations showed a high spatial turnover between field crops and orchards. But within each group, there was considerable overlap in the composition underlining the value of a heterogeneous landscape in maintaining spider diversity.

INTRODUCTION

Spiders—belonging to the order Araneae, the seventh largest order of the animal kingdom—are small invertebrate animals distributed throughout the world. The total number of described species of spider from all over the world is 43,244. They belong to 3879 genera under 111 families (Platnick 2012). In India, there are 1442 spider species in 361 genera belonging to 59 families (Siliwal *et al.* 2005). Spiders have been known to occupy almost every terrestrial habitat (Preston-Mafham and Preston-Mafham 1993) including cultural habitats.

As a land use, agriculture has contributed to modification and destruction of natural habitats of spiders. Apart from the usual natural factors, spider diversity in agro-ecosystems is influenced by farming activities such as tillage, irrigation, fertilization, weeding, crop establishment and pesticide application (Parris 2001) and inherent properties such as monoculture and intensification (Rypstra *et al*. 1999, Oberg 2007, Abhilash and Singh 2009). One underlying reason is the lower levels of vegetation diversity compared with natural habitats. Yet, numerous spider species have been successful in occupying various agro-ecosystems to a large extent (Young and Edwards 1990). Studying and exploring spiders in agro-ecosystems is essential for two reasons.—first, they represent an important component of animal diversity of a given site, and second, they contribute to an increased yield by controlling insect pest populations.

Worldwide, the spider fauna in agricultural landscapes has been studied extensively for its composition and population densities (e.g. Bishop & Riechert 1990, Marc et al 1999, Lee & Kim 2001, Sebastian *et al.* 2005, Sudhikumar *et al*. 2005 etc.). Similarly, some work has also been done in fruit orchards in other countries (Marc and Canard 1997, Brown *et al*. 2003, Tavares 2007, Monzo *et al*. 2011 etc.), but very little has been done in India (Sugumaran *et al*. 2007).

The Konkan, which is a part of the famous Western Ghats-Sri Lanka biodiversity hotspot, is speculated by the authors to hold a rich diversity of spiders. However, very little documentation of the spider diversity of this region exists in the literature (Pradhan 2006). There is a complete lack of published reports on the spider diversity and abundance in agricultural fields in this region. We present here results of a study of spider diversity in an agriculture-dominated landscape in the Konkan. The study landscape was assumed to be simplistic (as in the dominant agricultural pattern in Konkan), comprising two crop systems (rice, finger millet) and two orchard systems (cashew, mango) for the purposes of landscape-level attributes of spider assemblages.

STUDY SITE

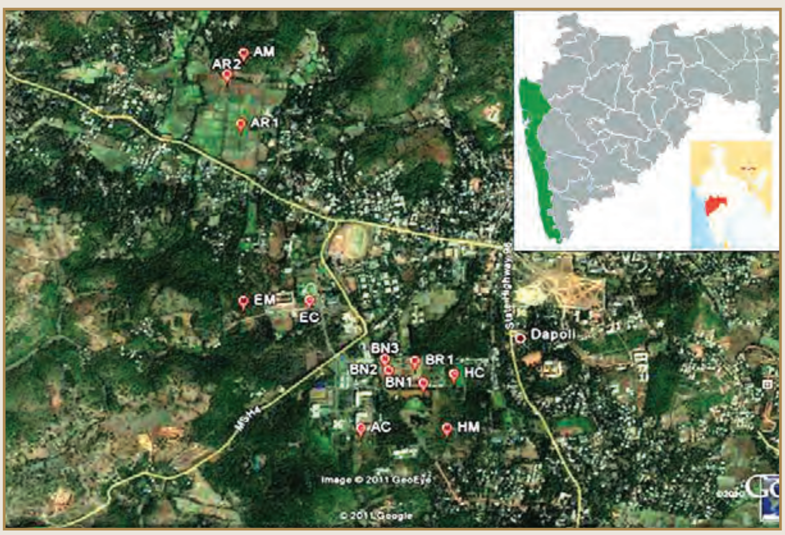
The Konkan is a coastal belt of land sandwiched between high hills of the Western Ghats in the east and the Arabian Sea in the west. The terrain is mostly hilly, fragmented by several short rivers originating in the Sahyadris and rushing to the Arabian Sea. Some areas in the region have coastal plains. The altitude varies from sea level to over 1000 m above MSL. The major landforms include coastal plains, creeks and estuaries, forested slopes, grassy hilltops and precipitous mountainsides. Agricultural land uses include flooded and upland paddies and finger millet on the hill-slopes and fruit orchards in the hills. A large proportion of land (>40%) is covered with forests (FSI 2011). The forests are mostly dry deciduous and moist deciduous mixed forests.

The region is characterized by a humid climate with over 3500 mm average annual rainfall and moderate temperatures ranging from as low as 7.5°C to as high as 38.5°C. The average relative humidity ranges from 55% to 100%. During the study period, the maximum and minimum temperatures ranged from 31°C to 32°C and from 18°C to19°C, respectively. The total rainfall received during the period of study was 4801.3 mm in 149 rainy days. The intensity of rainfall was higher during July and September. The relative humidity during the crop period ranged from 95% to 71.2%.

The Konkan region is famous for its rice (*Oryza sativa*) cultivation. In addition, finger millet (*Elusine corocana*) is also cultivated on hill-slopes. Recently, the area under cultivation of horticulture crops such as mango (*Mangifera indica*) and cashew (*Anacardium occidentale*) has also increased. In the Konkan region, rice, finger millet, cashew and mango are cultivated on 4.13, 0.47, 1.75 and 1.75 lakh ha, respectively (Magar *et al*. 2006, www.maccia.org.in, www.shivrai.co.in).

The main campus of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth in Dapoli, was selected for a landscape-level study of spider diversity. A map of the Konkan region showing the study site is presented in Fig1.

Figure 1.



The campus is spread over 200 ha. Various departmental farms cultivate different crops and maintain orchards

METHODS

SAMPLING FOR SPIDERS

A sample in the field crop was 15 minutes of visual search at a random location, usually restricted to an area of 1 m^2. Following Sebastian *et al*. (2005), the area around each plant in the area was searched for spider webs, and all plant parts were examined for spiders by a visual search and using the hand picking method. A sample in an orchard was 30 minutes of visual search of and around a fruit tree. Spiders were recorded by web visualization and using the branch collecting and hand picking methods. The ground under the canopy of the sample tree, the bark of its main stem and primary branches, and the foliage up to a height of 2 m above the ground were thoroughly searched for spiders. Each crop field was sampled every week from the first week of July 2010 to the first week of November 2010. Each orchard was sampled once every fortnight from the first fortnight of June 2010 to the last fortnight of March 2011. Four samples were collected from each field during one sampling instance.

After one reference spider was collected, others closely matching it were not collected. But those presenting confusion over identity in the field were collected for further exploration. The collected spiders were preserved in 70% ethanol, as suggested in Marc *et al*. (1999), with proper labeling, and deposited in the collection of the College of Forestry, Dapoli.

IDENTIFICATION OF SPIDERS

Even the latest checklists of Indian spiders have fewer than 1500 spiders (Siliwal *et al*. 2005)—less than 5% of the world's spiders. Compared with other megadiverse countries, this is only a small fraction. Thus, it seems that the spider fauna of India is inadequately explored. Further, there is a lack of elaborate identification keys, making it difficult for lay workers to fully identify species with certainty. In this study, the available reference material (Sebastian and Peter 2009, Proszynski 2009, Barrion and Litsinger 1995) was used, and online resources (www.southindianspiders.org, www.spidersofcentralindia.org etc.) were also referred to. The help of Dr. G. N. Vankhede of SGB University, Amravati, and Dr. S. K. Jose of Deva Matha College, Kuravilangadu, Kerala, was taken for identification of spiders on the basis of specimens and/or photographs. The individuals were put into uniquely coded morphospecies until further identification was possible.

INVENTORY COMPLETENESS

Inventory completeness is an important aspect of biodiversity inventories. It is defined as the ratio of observed to estimated species expressed as a percentage. A staggering number of species estimators based on presumably incomplete inventories are available (Walther and Martin 2001). However, according to them, Chao1, Chao2, Jackknife1 and Jackknife2 are the most reliable. The values of these estimators for spider assemblage in each of the agro-ecosystem were calculated using the EstimateS software package (Colwell 2009). This software also calculated the numbers of singletons (species with only one individual) and doubletons (species with only two individuals). The range of per cent completeness was calculated by dividing the observed species richness by each estimator. Along with these, the average number of individuals per sample and the average number of species per sample were also calculated for each agro-ecosystem. The sampling intensity is also considered as a measure of inventory completeness. It was calculated as the number of individuals collected per species.

SPECIES DIVERSITY

The diversity of a community is assessed in terms of its species richness—the observed number of species—first and foremost. Since inventories are always incomplete, the estimated number of species, calculated as described in the previous section, is a more reliable measure of the species richness. In addition, diversity indices such as Simpson's index (D) and Shannon's index (H') are used to explore the apportionment component of the diversity of a community (Magurran 2004). Simpson's index shows whether a community is dominated by one or a few species. Shannon's index, on the other hand, assesses the heterogeneity of species abundances within a community. Various transformations are available for easy interpretation of D and H', like 1/D, 1-D and 1/H'. But it was decided to use the straightforward calculated figures. Thus, a higher value of D in the results indicates a high dominance of one or few species, making the community less diverse. On the other hand, a higher value of H' indicates a high degree of heterogeneity within the community and hence higher diversity.

The diversity of a community within a given habitat is alternatively termed as the alpha diversity; that between two habitats within a landscape is termed the beta diversity (Whittaker 1972 as adopted in Magurran 2004). The species richness, D and H' all represent the alpha diversity of spider communities in particular agro-ecosystems. Whittaker's β values were also calculated for pairs of agro-ecosystems. The results of this analysis are presented as the spatial turnover at the species and family levels between pairs of agro-ecosystems. The higher the value of Whittaker's ***β*** is, the higher the turnover between those two communities, indicating minimal compositional overlap.

RESULTS

In this study, a total of 4035 individual spiders were recorded. These were identified, as far as possible, to the species level using the techniques described in the previous section. After exhausting all the available resources for identification, it was determined that these belonged to 141 species under 21 families. Of these, 65 species could be identified to the species level with certainty. The remaining species could be identified up to the genus level (67) or the family level (9). A checklist of the spider species recorded in this study is given in Appendix I. The dominant families were the families Araneidae and Salticidae, with 35 and 34 species, respectively. Similarly, the maximum number of species was also recorded in the families Araneidae (15) and Salticidae (16).

A summary of the observations is provided in Table 1. Mango agro-ecosystems had the highest observed species richness, whereas rice had the lowest. However, they cannot be compared validly because of the completely different types of habitats and sampling units. Thus, between mango and cashew agro-ecosystems, mango was more species-rich, with 98 species, compared with 69 in cashew. Similarly, between rice and finger millet, finger millet was more species-rich, with 35 species, compared with 29 in rice agro-ecosystems. Similar trends were observed in the case of the number of genera. In terms of the number of families, rice and finger millet had the same number. However, cashew had only two thirds of the families recorded in mango.

Table 1.

Summary of observations on spiders in major agro-ecosystems of Konkan region

Agroecosystem	Sampling unit	N	Individuals	Families	Genera	Species	D	H'
Rice	Quadrant	204	526	7	14	29	0.103	2.73
Finger millet	Quadrant	192	423	7	19	35	0.081	2.81
Cashew	Tree	240	743	14	43	69	0.054	3.41
Mango	Tree	240	2343	21	60	98	0.119	3.02
Total		4035	21	70	141			

The ranges of per cent completeness based on the minimum and maximum estimates for each system are presented in Table 2. For comparison, the values of the observed species richness, sampling intensity, singletons and doubletons are also provided in the same table. The sampling intensity was found to be highest in mango and lowest in cashew. The combined proportion of singletons and doubletons with observed species richness ranged from 34% in the case of rice and 41% in the case of cashew. Two commonly used diversity indices were also worked out for each agro-ecosystem and are presented in Table 1.

The compositions of spider families in different systems under study are presented in Table 3. Rice and finger millet agro-ecosystems had equal numbers of families recorded. Whereas the family Thomisidae was found only in rice, the family Oonopidae was found only in finger millet. The remaining six families were shared by these two agro-ecosystems. The family Tetragnathidae was dominant in rice, with 7 species. On the other hand, the families Araneidae and Salticidae were the dominant families in finger millet, with 13 species each. Similarly, the family Araneidae was the dominant family in both cashew and mango orchards (21 and 26 species, respectively), followed by the family Salticidae (16 and 21 species, respectively). The families Corinnidae, Ctenidae, Filistatidae, Miturgidae, Philodromidae and Sparassidae were the rare spider families in the landscape, with only one species each and found only in one agro-ecosystem, i.e. mango orchards. None of the families were found exclusively in cashew orchards.

To note the contribution these varied ecosystems make to the spider assemblages of the landscape, the beta diversity was explored. The beta diversity values (Whittaker's ***β***) were worked out at the family and species levels. The values are presented in Tables 4 and 5, respectively.

Table 2.

Comparison of observed spider species richness with various estimates for assessment of inventory completeness in agro-ecosystems under study

Parameters	Rice	Finger millet	Cashew	Mango
No. of individuals	526	423	743	2343
Individuals/sample	2.58	2.20	3.10	9.76
Observed species richness	29	35	69	98
Species per sample	1.81	1.74	2.24	4.29
Sampling intensity	18.14	12.09	10.77	23.91
Singletons	6	12	17	22
Doubletons	4	2	11	14
Chao1	34	71	82	115
Chao2	34	53	85	113
Jackknife1	35	47	88	120
Jackknife2	37	55	96	126
Completeness (%)	78-85	49-75	72-84	78-87

Table 3.

Composition of spider families in important agro-ecosystems of Konkan region

Family	Rice	Finger millet	Cashew	Mango	Total
Araneidae	5	13	21	26	35
Clubionidae	-	-	1	1	1
Corinnidae	-	-	-	1	1
Ctenidae	-	-	-	1	1
Filistatidae	-	-	-	1	1
Gnaphosidae	-	-	1	1	2
Hersiliidae	-	-	1	1	1
Lycosidae	6	2	3	2	6
Miturgidae	-	-	-	1	1
Nephilidae	-	-	1	2	2
Oonopidae	-	1	-	1	1
Oxyopidae	1	2	6	5	7
Philodromidae	-	-	-	1	1
Pholcidae	-	-	1	1	1
Pisauridae	-	-	1	2	2
Salticidae	6	13	16	21	34
Sparassidae	-	-	-	1	1
Tetragnathidae	7	3	4	4	9
Theridiidae	2	1	9	10	15

Thomisidae	2	-	3	6	10
Uloboridae	-	-	1	9	9
No. of families	7	7	14	21	21

Table 4.

Contribution of different agro-ecosystems to landscape-level diversity of spider families in terms of beta diversity

Agroecosystems	Total families	Common families	Exclusive to first system	Exclusive to second system	Turnover (*β*)
Rice-finger millet	8	6	1	1	0.1429
Rice-cashew	15	6	1	8	0.4286
Rice-mango	21	7	0	14	0.5000
Finger millet-cashew	15	6	1	8	0.4286
Finger millet-mango	21	7	0	14	0.5000
Cashew-mango	21	14	0	7	0.2000

Table 5.

Contribution of different agroecosystems to landscape-level diversity of spider species in terms of beta diversity

Agroecosystem	Total species	Common species	Exclusive to firstsystem	Exclusive to second system	Turnover (*β*)
Rice-finger millet	54	10	19	25	0.6875
Rice-cashew	88	10	19	59	0.7959
Rice-mango	118	9	20	89	0.8583
Finger millet-cashew	86	18	17	51	0.6538
Finger millet-mango	115	18	17	80	0.7293
Cashew-mango	110	57	12	41	0.3174

DISCUSSION

INCOMPLETE IDENTIFICATION

It is clear that identification of spider individuals to species level was not possible in this study. The identification carried out by the first two authors was vetted by two spider taxonomists. And still the identification was incomplete. But high levels of incomplete identification are frequent in spider studies. For example, Jose *et al*. (2008) reported 7 species identified up to the family level and 39 up to the genus level from a total of 147 species. Similarly, Uniyal and Hore (2009) reported 65 species—among 160—that were identified only up to the genus level. Pearce *et al*. (2004) also could identify only 28 up to the species level, 50 up to the genus level and 24 to the family level. This is because of a lack of useful reference material for identification and the time required for conventional taxonomic work.

The solution to this problem is to use a morphospecies approach. A morphospecies is a group of organisms thought to be of one species only on the basis of their apparent morphological features (Derraik *et al*. 2002). Although Derraik *et al*. (2002) themselves pointed out that unreliable body colour, sexual dimorphism and indistinct immatures made the morphospecies approach less reliable in the case of spiders, Hore and Uniyal (2008a) recommended the morphospecies approach in the case of poorly known and species-rich taxa such as spiders in studies in India. The cautionary principle here is to always remember that the estimates of diversity might be slight over- or underestimates with the morphospecies approach (Derraik *et al*. 2010).

INVENTORY COMPLETENESS

Chao *et al*. (2005) emphasized the fact that recording all species in a species-rich assemblage with a large proportion of rare species was literally impossible due to sampling limitations. But the objective of any diversity study is always near-complete surveys, based on which further valid inferences can be drawn. This completeness of surveys is usually understood on the basis of proportion of estimated species that are actually recorded (Uniyal and Hore 2009). There are dozens of species richness estimators, out of which the Chao and Jackknife estimators were found to be the least biased and most precise in the case of bird inventories (Walther and Martin 2001). Hore and Uniyal (2008b) used Chao1 and Jackknife2 estimators for assessing the completeness of spider inventories in India's Terai Arc Conservation Area.

In the present study, the minimum completeness was recorded in finger millet (49-75%), whereas relatively high completeness (72-87%) was recorded in the other three agroecosystems. Whereas Chao1 estimated the highest species richness for finger millet, Jackknife2 estimated the highest values for the other three agroecosystems. Hore and Uniyal (2008b) obtained completeness estimates for spider inventories that varied from 56% to 92% in different forest vegetation types. Taking a cue from them, it was concluded that the present study had fairly complete surveys in rice, cashew and mango but the surveys were less complete in finger millet.

DIVERSITY IN INDIVIDUAL SYSTEMS

Barrion and Litsinger (1995) recorded 342 species of spider from rice fields in South Asian and Southeast Asian countries. They also showed that the spider diversity of rice fields in irrigated wetlands was higher than that of rain-fed wetlands. Sebastian *et al.* (2005) collected 92 species of spider from irrigated rice fields in the Kharif and Rabi seasons in 2002-03 at six sites at different altitudes in two districts of Kerala. Sudhikumar *et al*. (2005) also recorded 94 spider species from lowland rice fields in Kerala over 2 years in four cropping seasons. The low species richness in the rice agroecosystem noted in the present study could be attributed to the fact that sampling was carried out during only one season and the extent of the study site in terms of area and altitude was limited. Employing different sampling techniques for different groups of spiders might have been a better strategy. A similar situation was found in the finger millet agroecosystem. However, this is perhaps the first record of the spider species associated with finger millet. The species richness was not much higher than that of the rice agroecosystem, probably because of the above-mentioned reasons.

Sugumaran *et al.* (2007) found a species richness of 13 in fruit trees in the horticultural research station at Yercaud, in Tamil Nadu. In the present study, a species richness several times higher was recorded in both the cashew and mango ecosystems. In fact, Sugumaran and colleagues collected spiders by net-sweeping in addition to hand-picking. They have not mentioned their study period or sampling intensity, thus making it difficult to compare the species richness values. The present work is also, perhaps, the first systematic report of spiders associated with cashew and mango agroecosystems.

The value of Simpson's index of dominance (D) in rice was relatively higher than that in finger millet, meaning there was a very high dominance of a few spider species in the rice ecosystem. Similarly, D in mango was much higher compared with cashew, indicating that the spider assemblage in the mango agroecosystem was dominated by a few species, whereas that in cashew had a comparatively large number of rare species. The value of Shannon's index (H') similarly indicated a higher diversity in finger millet and cashew compared with rice and mango, respectively. It is an interesting observation that even though the mango ecosystem had a higher species richness, it showed lower diversity compared with the cashew ecosystem.

CONTRIBUTION TO LANDSCAPE-LEVEL DIVERSITY

Whittaker's ***β*** gives an idea about the compositional dissimilarity between two sets of taxon assemblages. It is also called the spatial turnover. In spiders, the family is a very useful taxon for comparison of different habitats because identification at the genus and species levels is very complicated and almost always incomplete. Churchill (1998) even described how spider families could be used as cost-effective indicators of ecological change and disturbance in tropical Australia. We found that the highest turnover of spider families was between mango and agricultural crops (0.50), followed by that in cashew and agricultural crops (0.43). The lowest turnover was recorded between pairs of agricultural crops and horticultural crops (0.14 and 0.20, respectively).

When the beta diversity was worked out at the species level, it was found that the maximum turnover was between rice and mango systems (0.86) and the minimum turnover was between cashew and mango systems (0.32). Thus, a vast proportion of the spider assemblage diversity at the landscape level was contributed by horticultural crop orchards, but a high level of compositional dissimilarity existed between agricultural and horticultural crops. This was indicative of the important contribution of agricultural crops to the spider diversity in the landscape. This was a clear indication of the existence of distinct assemblages in agricultural crops, in contrast with horticultural crops. Interestingly, however, the spider assemblage in finger millet was somewhat closer to that in cashew, compared with rice.

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APPENDIX I

Checklist of species recorded in important agroecosystems of Konkan region. Plus sign indicates presence of that species in a particular agroecosystem. A total of 141 morphospecies belonging to 21 families were recorded.

Sl. no.	Code	Morphospecies	Rice	Finger millet	Cashew	Mango
Araneidae						
1	Aran	*Arachnura angura*			+	+
2	Ra3	*Araneid1*	+			
3	Na8	*Araneid2*		+		
4	Armi	*Araneus mitificus*			+	
5	Arne	*Araneus nexcelsus*				+
6	Aransp1	*Araneus sp1*		+		
7	Aransp2	*Araneus sp2*				+
8	Arae	*Argiope aemula*	+	+		
9	Arpu	*Argiope pulchella*	+		+	+
10	Arsp	*Argiope sp1*				+
11	Cyco	*Cyclosa confusa*		+	+	+
12	Cyhe	*Cyclosa hexatuberculata*		+	+	+
13	Cyin	*Cyclosa insulana*		+	+	+
14	Cyku	*Cyclosa kumadai*		+	+	+
15	Cymu	*Cyclosa mulmeinensis*			+	+
16	Cysp1	*Cyclosa sp1*		+	+	+
17	Cysp2	*Cyclosa sp2*			+	+
18	Cysp3	*Cyclosa sp3*			+	+
19	Cysp4	*Cyclosa sp4*				+
20	Cersp	*Cyrtarachne sp1*		+		
21	Cyci	*Cyrtophora citricola*		+	+	+
22	Cyrsp	*Cyrtophora sp1*			+	+
23	Erla	*Eriovixia laglaisei*			+	+
24	Ersa	*Eriovixia sakiedaorum*			+	+
25	Ersp	*Eriovixia sp1*				+
26	Gesu	*Gea subarmata*				+
27	Laar	*Larinia argiopiformis*	+		+	+
28	Nebe	*Neoscona bengalensis*			+	+
29	Nemu	*Neoscona mukerjei*	+	+	+	+
30	Nena	*Neoscona nautica*		+	+	
31	Nesp1	*Neoscona sp1*		+		
32	Nesp2	*Neoscona sp2*			+	
33	Nesp3	*Neoscona sp3*				+
34	Pade	*Parawixia dehaani*				+
35	Thbr	*Thelacantha brevispina*			+	+

Clubionidae						
36	Clsp1	*Clubiona sp1*			+	+
Corinnidae						
37	Caze	*Castianeira zetes*				+
Ctenidae						
38	Ctsp	*Ctenus sp1*				+
Filistatidae						
39	Prsp	*Pritha sp1*				+
Gnaphosidae						
40	Gnsp	*Gnaphosa sp1*			+	
41	Posp	*Poecilochroa sp1*				+
Hersiliidae						
42	Hesa	*Hersilia savignyi*			+	+
Lycosidae						
43	Hiag	*Hippasa agelenoides*	+	+	+	+
44	Lyma	*Lycosa mackenziei*	+		+	
45	Lysp	*Lycosa sp1*	+			
46	Paps	*Pardosa pseudoannulata*		+	+	+
47	Pasp2	*Pardosa sp1*	+			
48	Pasp1	*Pardosa sp2*	+			
Miturgidae						
49	Chesp1	*Cheiracanthium sp1*				+
Nephilidae						
50	Hemu	*Herennia multipuncta*				+
51	Nepi	*Nephila pilipes*			+	+
Oonopidae						
52	Opin	*Opopaea indica*		+		+
Oxyopidae						
53	Hasp2	*Hamataliva sp1*			+	+
54	Hasp1	*Hamataliva sp2*			+	
55	Hasp3	*Hamataliva sp3*			+	+
56	Oxbi	*Oxyopes birmanicus*	+	+	+	+
57	Oxdi	*Oxyopes dineshi*				+
58	Oxja	*Oxyopes javanus*		+	+	+
59	Oxsh	*Oxyopes shweta*			+	
Philodromidae						
60	Tisp	*Tibellus sp1*				+
Pholcidae						
61	Utat	*Uthina atrigularis*			+	+
Pisauridae						
62	Pesp	*Perenethis sp1*				+
63	Pigi	*Pisaura gitae*			+	+
Salticidae						
64	Aste	*Asemonea tenuipes*			+	+
65	Bral	*Brettus albolimbatus*				+

66	Caba	*Carrhotus barbatus*		+		
67	Car	*Carrhotus sp1*	+	+	+	+
68	Cavi	*Carrhotus viduus*	+	+	+	+
69	Caxa	*Carrhotus xanthogramma*		+		+
70	Chla	*Chrysilla lauta*		+		
71	Chve	*Chrysilla versicolor*			+	+
72	Epin	*Epeus indicus*			+	+
73	Epsp	*Epeus sp1*			+	+
74	Epau	*Epocilla aurantiaca*			+	+
75	Euo	*Euophrys sp1*		+		
76	Habr	*Harmochirus brachiatus*				+
77	Haad	*Hasarius adansoni*				+
78	Hyse	*Hyllus semicupreus*			+	+
79	Masp	*Marpissa sp1*				+
80	Mebi	*Menemerus bivittatus*			+	+
81	Myin	*Myrmarachne inermichelis*			+	+
82	Myja	*Myrmarachne japonica*		+	+	
83	Mysp	*Myrmarachne sp1*			+	+
84	Pisp	*Phidippus sp1*				+
85	Phsp	*Phintella sp1*	+	+		
86	Phvi	*Phintella vittata*		+	+	+
87	Plpa	*Plexippus paykulli*		+		
88	Rhsp1	*Rhene sp1*			+	+
89	Rhsp2	*Rhene sp2*			+	+
90	Rs1	*Salticid1*	+			
91	Rs2	*Salticid2*	+			
92	Rs4	*Salticid3*	+			
93	Rs5	*Salticid4*	+			
94	Ns6	*Salticid5*		+		
95	Ns7	*Salticid6*		+		
96	Ns9	*Salticid7*		+		
97	Tedi	*Telamonia dimidiata*			+	+
Sparassidae						
98	Olmi	*Olios milleti*				+
Tetragnathidae						
99	Lede	*Leucauge decorata*	+	+	+	+
100	Tece	*Tetragnatha ceylonica*			+	+
101	Teco	*Tetragnatha cochinensis*	+			
102	Teex	*Tetragnatha extensa*	+	+		
103	Tema	*Tetragnatha mandibulata*	+	+	+	+
104	Tesp1	*Tetragnatha sp1*	+			
105	Tesp3	*Tetragnatha sp2*			+	+
106	Tesp2	*Tetragnatha sp3*	+			
107	Tevi	*Tetragnatha viridorufa*	+			

Theridiidae						
108	Aclu	*Achaearanea lunata*			+	+
109	Achsp1	*Achaearanea sp1*			+	
110	Achsp2	*Achaearanea sp2*				+
111	Anex	*Anelosimus exiguus*			+	+
112	Arbo	*Argyrodes bonadea*				+
113	Argsp1	*Argyrodes sp1*			+	+
114	Argsp2	*Argyrodes sp2*				+
115	Arfl	*Ariamnes flagellum*	+			
116	Arisp1	*Ariamnes sp1*			+	+
117	Arisp2	*Ariamnes sp2*			+	
118	Chsp	*Chrysso sp1*			+	+
119	Col	*Coleosoma sp1*		+		
120	Rosp	*Romphaea sp1*	+			
121	Thesp1	*Theridion sp1*			+	+
122	Thesp2	*Theridion sp2*			+	+
Thomisidae						
123	Amfo	*Amyciaea forticeps*				+
124	Thosp1	*Diaea sp1*	+			
125	Misp	*Misumena sp1*			+	
126	Oxsp1	*Oxytate sp1*			+	+
127	Oxsp2	*Oxytate sp2*				+
128	Oxsp3	*Oxytate sp3*				+
129	Resp	*Regillus sp1*	+			
130	Thosp2	*Thomisus sp1*			+	
131	Thosp3	*Thomisus sp2*				+
132	Xysp	*Xysticus sp1*				+
Uloboridae						
133	Ulsp1	*Uloborus sp1*			+	+
134	Ulsp2	*Uloborus sp2*				+
135	Ulsp3	*Uloborus sp3*				+
136	Ulsp4	*Uloborus sp4*				+
137	Ulsp5	*Uloborus sp5*				+
138	Ulsp6	*Uloborus sp6*				+
139	Ulsp8	*Uloborus sp7*				+
140	Ulsp9	*Uloborus sp8*				+
141	Ulsp7	*Zosis geniculata*				+

POLLINATORS IN CHANGING LANDSCAPE OF AGRICULTURE: GLOBAL AND INDIAN SCENARIOS

Parthiba Basu[1] **& Mahua Ghara**[2]

1. Department of Zoology, University of Calcutta, Kolkata, West Bengal, India.

2. Centre for Pollination Studies, University of Calcutta, Kolkata, West Bengal, India.

email: bparthib@gmail.com

POLLINATION AND POLLINATORS

Pollination results in fruit set, upon which many animals are dependent, including human beings. Insects that provide pollination services provide an important ecosystem service upon which 60–90% of plant species are dependent (Kremen *et al*. 2007). The economic value of pollination worldwide as stated by Simon Potts, a leading scientist in pollination ecology, is thought to be between £30 billion and £70 billion each year (Kluser and Peduzzi 2007). About one third of crop production depends on animal pollinators (Kremen *et al*. 2007), and over 70% of tropical crops are dependent on pollination services (Roubik 1995, Klein *et al.* 2007) that are provided predominantly by insects. Even those crops that can set seeds and produce fruits with self-pollination have been shown to give higher yields when cross-pollinated. With respect to the value of insect pollination, vegetables and fruits are among the leading crops, followed by edible oil crops, stimulants, nuts and spices (Gallai *et al.* 2009).

LOSS OF POLLINATORS AND IMPORTANCE OF HONEYBEES

A major concern worldwide is the loss of pollinators for crops, which reduces the yield of pollinator-dependent crops and hence is linked directly to food security in the present scenario of an increasing world population. If the pollinator decline continues and measures are not taken, the world could face serious problems in terms of its food and nutrition supply (Kevan and Phillips 2001).

Pollinators important for crops include domesticated bees such as the honey bee *Apis mellifera* or wild bees. Domesticated bees were found to be sufficient for meeting pollination needs, but the latest findings indicate a decline both in domesticated bees and wild bees (Potts *et al*. 2010). The decline could be attributed to many anthropogenic factors such as agricultural intensification, habitat fragmentation, loss of habitat, use of agrochemicals and non-anthropogenic factors such as diseases and alien species (Potts *et al*. 2010). Also, the interaction between crop and pollinator could break down or weaken indirectly from changes in floral properties due to global environment changes (Tylianakis *et al*. 2008, Hoover *et al*. 2012).

Investigations have found and continue to find that honey bees are economically important for crops. However, in the face of collapses in managed bee colonies, as is now one of the major concerns in the Western nations, native wild bees could provide insurance against the loss of domesticated bees (Winfree *et al*. 2007). Garibaldi *et al*. (2011a) observed that fruit set was positively related to visitations by wild pollinators and not by honey bees, indicating the importance of wild pollinators for pollination of crops. Also, if native bees are as high in number as managed bees, they could complement the services provided by honey bees (Rader *et al*. 2009). Alongside a loss in total abundance of bees, a species meltdown would adversely affect the stability of pollination services (Ricketts 2004).

LANDSCAPE ELEMENTS AND POLLINATION

The wild population could be affected by landscape elements. For example, a study conducted by Carré *et al*. (2009) has shown that the abundance of wild bees in Europe is dependent upon landscape elements such as semi-natural habitats and crop habitats. Crop habitats with more native vegetation have greater numbers of bee species compared with habitats with less natural vegetation (Cunningham *et al*. 2012).

Proximity to natural habitats could be beneficial for obtaining pollination services as it has been found that pollination services decline as the distance from a natural habitat increases (Ricketts *et al*. 2008, Carvalheiro *et al*. 2010, Garibaldi *et al*. 2011a).

Nesting resources could also be important for structuring bee communities through the availability of locations for nesting or nest-building materials (Potts *et al.* 2005, Chaplin-Kramer *et al*. 2011). Thus, conserving natural habitats could help maintain naturally occurring pollinator species, ensuring pollination services in agricultural fields (Ricketts *et al*. 2008, Rader *et al*. 2009).

INTERNATIONAL MEASURES AND CURRENT UNDERSTANDING

The pollination crisis and food insecurity have led to many global initiatives and collaborations aimed at quantifying the crisis, identification of species and the causes of loss of wild as well as domesticated bees (for example, the ALARM project, FAO Global Pollination Project). The pollination crisis, caused by incomplete pollen delivery by pollinators, has been attributed to the availability of fewer pollinator individuals because of the factors leading to a pollination decline (as mentioned above). The crisis leads to a mean decrease in the crop yield, to compensate for which more land is converted to agricultural fields (Garibaldi *et al.* 2011b). Also, in both developed and developing countries, a greater area is under pollinator-dependent crops (Aizen *et al.* 2008, Winfree 2008). It is therefore suggested that land use policies should restore and preserve natural habitats within the agricultural landscape, which should enhance pollination services (Garibaldi *et al.* 2011a). A basic understanding of the behaviour, ecology and foraging pattern of the pollinators is also important (Cunningham *et al*. 2012, Kevan and Menzel 2012) for this can help us take decisions on restoration measures.

POLLINATION CRISIS IN THE INDIAN CONTEXT

India has the second largest extent of arable land, and this is present in various bioclimatic zones. According to a 2009 World Bank report, the percentage area of agricultural land in India was 60.53 in 2009 (Trading Economics 2009). Many crops cultivated in India are pollinator dependent (Abrol 1993);and crops have been found to be associated with as well as dependent on many species of wild bee such as *Xylocopa* and *Apis* spp. as well non-apid bees such as members of the family Megachilidae (Thomas *et al*. 2009).

Though pollination limitation has been observed in wild varieties (Somanathan and Borges 2000, Sharma *et al*. 2011) whether such a problem exists in crop plants is not very well known. A study from the Himalayan region revealed that beekeeping has increased the yield of apples besides other crops, indicating the importance of pollinators and hinting at pollinator limitation. A recent analysis by Basu *et al*. (2011) of the vegetable yield from India over 45 years, using FAO data, indicates that there is pollination limitation in Indian agriculture. This is the first such report from India. Pesticides have been found to play a role in the decline of pollinators in the Himalayan region, which has affected the apple yield (Partap and Partap 2009). India is one of the most vulnerable countries due to the extensive pesticide-dependent agriculture that has been practised in the country over the last four decades and the fast-changing land use. A set of developing countries that use pesticides intensely and have lost forest cover are at greater risk of pollination limitation as observed by Basu *et al.* (unpublished).

LAND USE PATTERN AND POLLINATION IN INDIAN CONTEXT

According to a Monitoring Agri-trade Policy (MAP) report published in 2007, 60% of farmers in India have less than 1 hectare of land for cultivation. The average size of holdings has declined over time mainly because big farms have been divided on inheritance. Medium to large farms constitute just over 7% of all holdings. The land use and the crop acreages have also changed (Purushothaman and Kashyap 2010). Crops could be cultivated for sustenance or for their commercial value. Therefore, the pollinator requirements of a crop field depend on the size of the field and the types of crops cultivated. The effects of land use on pollinators in India are yet to be tested, and restoration of suitable habitats within the agricultural landscape may be required for the survival of pollinator species. However, as Ghazoul (2007) has warned, in a country like India, where the farmers are dependent on maximum returns from the land, the ecosystem approach, and hence saving pollinator-friendly sites, could be a problem.

Thus, there is an urgent need to assess the pollinator diversity as well as the pollinator requirements using standardised protocols. There is a serious gap in the quantitative data on pollination limitation in crop fields in various agro-ecological regions of the country, and this gap has to be bridged immediately. Finally, pollination limitation and land use patterns should be looked at together to correlate the land use pattern with such observations. These measures will help us understand the value of pollinators for crops in the changing agricultural landscape of India.

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HIGH-ALTITUDE BUTTERFLY FAUNA OF GANGOTRI NATIONAL PARK, UTTARAKHAND: PATTERNS IN SPECIES, ABUNDANCE COMPOSITION AND SIMILARITY

Manish Bhardwaj and V.P. Uniyal
Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand, India
email : uniyalvp@wii.gov.in

ABSTRACT

Mountain habitats have been under severe threats due to the enormous population increase during the last few decades, and thus it is important to conserve biodiversity in these landscapes before many species go extinct. Due to the focus on larger charismatic species in conservation, less glamorous and abundant taxa remain neglected. We studied butterfly diversity in Gangotri National Park, Uttarakhand, India during April-November 2008. Butterflies were sampled along 29 transects in Gangotri and Nilang valleys. Transects were distributed across various elevations, ranging from 2800 m amsl to 5200 m amsl. The vegetation in the park is very diverse and falls within five forest types due to the variations in topography, climate, aspect and elevation. A total of 1639 butterfly individuals representing 34 species, 29 genera and five families were recorded during the study. The highest butterfly species richness, abundance and diversity were recorded in Himalayan dry/moist temperate forest. The highest number of unique species was also recorded in Himalayan dry/moist temperate forest, and the number declined with increasing elevation. Among the five butterfly families, the highest species richness and abundance was accounted for by the family Nymphalidae. Three distinct butterfly communities were identified on the basis of cluster analysis that supported the idea that each vegetation type supports a distinct butterfly assemblage. About 47% of the butterflies were confined to a single vegetation type each, reflecting the specificity of their host plants. As most butterflies were found to be restricted to specific vegetation and elevation zones, regular monitoring and conservation of these habitats is important for conservation of butte flies and other biodiversity in the few remnant fragile high-altitude habitats.

INTRODUCTION

The Himalaya are part of the world's largest mountain complex and a buffer to major realms viz., the Oriental, Palaearctic and Ethiopian realms (Mani, 1994). Biogeographically, the Himalaya are categorized into two zones: (1) Zone 1, 1A Trans Himalaya (Ladakh Mountains) and 1B Tibetan plateau (b) Zone 2 is divided into four provinces (2A North Western, 2B Western, 2C Central and 2D Eastern Himalaya) (Rodgers et al., 2000). Rodgers and Panwar (1988) categorized the entire Himalayan region of Uttarakhand under one biogeographic province, the Western Himalaya (2B) (602,848 km^2). Gangotri National Park (NP) is the largest protected area (PA) in this zone and harbours a rich high-altitude biodiversity, which makes this PA important for protection and management of representative Western Himalayan biodiversity.

Drawing up an inventory of the biodiversity is of primary importance in biodiversity conservation for sustainable development, particularly in threatened and fragmented landscapes such as the Western Himalaya, which harbours a unique assemblage of flora and fauna of considerable conservation importance. In comparison with higher plants and larger animals, the inventory of insects in the Western Himalayan landscape is still fragmentary and incomplete. In order to know how and where to protect biodiversity, it is imperative that we learn more about the diversity of terrestrial arthropods, which may constitute 80% or more of the global diversity but have too often been neglected by resource managers and conservation planners (Wilson, 1988, 1992; Colwell & Coddington, 1994; Longino, 1994).

Assuming that carefully selected focal taxa can serve as a proxy for biodiversity overall (Kerr *et al*., 2000), several insect taxa have been tested for their utility as indicators in various ecosystems at multiple spatial scales (McGeoch, 1998). It has been suggested that butterflies have a role as indicators in conservation planning (Ehrlich & Murphy, 1987; Nelson & Andersen, 1994; DeVries *et al.*, 1997) and are often proposed as bioindicators of forest health and surrogate taxa for various biodiversity groups (Hayes *et al*., 2009). Butterflies meet many of the criteria proposed to define useful indicator groups: they have short

Highbrown Silverspot Fabriciana adippe: A rare butterfly that flies between 3500 and 5200 m in dry alpine scrub habitat in Nilang Valley

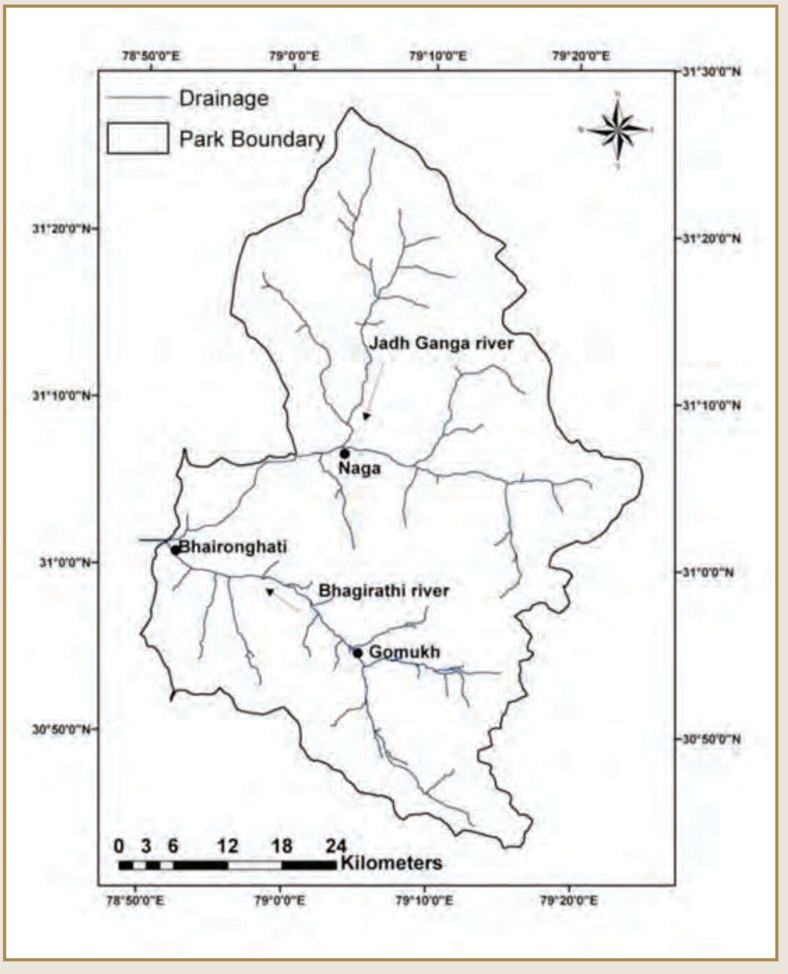
generation times, are day-flying, are diverse and are easily identifiable. Furthermore, butterfly taxonomy, distributions, and natural history are better studied than for any other insect taxon (Gilbert & Singer, 1975; Vane-Wright & Ackery, 1984). In the current paper, we studied the species richness, abundance and diversity of butterflies in various elevations and four major vegetation zones in Gangotri National Park, Uttarakhand in 2008. We assess the completeness of the inventory and document the family composition and community structure of butterflies. We discuss the similarity between the butterfly assemblages of different elevational transects.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in Gangotri National Park (NP) (30°50′-31°12′N, 78°45′-79°02′E), which is located in Uttarkashi District of the northern Indian state of Uttarakhand. It is the largest (2,390 km^2) protected area in the state. The north-eastern park boundary runs along the international boundary with China. The park area provides viable continuity with Govind National Park in the west and Kedarnath Wildlife Sanctuary in the south. The elevation ranges from 1,800 to 7,083 m amsl. It falls within biogeographical zone 2B of the western Himalaya (Rodgers & Panwar, 1988) (Fig. 1), including a considerable stretch of snow-clad mountains and glaciers. The Gangotri glacier, after which the park has been named, is one of the holy shrines of Hindus and is located inside the park. It attracts large numbers of tourists and pilgrims. High ridges, deep gorges, precipitous cliffs, crags, glaciers and narrow valleys characterize the area.

Figure 1.



Map of Gangotri National Park

A large variation in elevation and aspect inside the PA results in a diversity of vegetation, grouped in five major forests types (Champion & Seth, 1968):

1. Himalayan moist temperate forest

2. Himalayan dry temperate forest

3. Sub-alpine forest

4. Moist alpine scrub

5. Dry alpine scrub

Gangotri NP is accessible through two major river valleys, *viz*., Gangotri and Nilang valleys. Although, the entire NP was categorized under Western Himalaya (2B) by Rodgers & Panwar (1988), Nilang Valley and the surrounding region can be safely categorized under Trans-Himalaya (Zone 1) (Chandola *et al*., 2008). A historical account of Nilang Valley has been provided by Atkinson (1981). Very few studies or surveys have been conducted in the area. So far, 15 species of mammal and 150 bird species have been documented from within the park (Parmanand *et al*., 2000). Naithani (1988) provided a botanical account involving 170 species of flowering plant from a part of Gangotri NP.

PLATE I VEGETATION ZONES SAMPLED IN GANGOTRI NP

Himalayan moist temperate forest

Sub-alpine forest

Moist alpine scrub

Dry alpine scrub

DATA COLLECTION

We studied the butterfly diversity along Gangotri and Nilang valleys in Gangotri NP. We divided the above-mentioned forests into four sampling zones (Plate I). Zone I included the dry and moist temperate forests. A total of 29 random forest trails/transects were established to sample butterflies during April-November 2008, across three seasons (spring, summer and autumn). We sampled in areas ranging in elevation from 2600 m amsl to 5200 m amsl. All transects lengths were 500 m, and transects were traversed on foot within 45 min. We recorded all butterflies seen during each transect walk in an imaginary 5 × 5 × 5 (m^3) box around the observer. Abundance data were collected when the cloud cover was less than 70%, between 0900 and 1300 hrs, when the conditions are most favourable for butterfly flight. In addition to transects, we also used opportunistic sightings at mud puddles, nectar sources and other resource–rich sites to increase the inventory. Butterflies that could not be readily identified visually were either photographed or captured using a hand-held sweep net and were released after identification.

STUDY ORGANISM

We sampled all butterflies of the Hesperioidea and Papilionoidea (order Lepidoptera, suborder Rhopalocera). We documented five butterfly families (*i.e.* Hesperiidae, Papilionidae, Pieridae, Lycaenidae and Nymphalidae) and identified them to species level following Evans (1932), Wynter-Blyth (1957) and Haribal (1992). Here, we use the nomenclature of Kehimkar (2008).

DATA ANALYSIS

We pooled butterfly data from all transects falling within one vegetation zone. We considered the total number of species observed as the species richness and the number of individual butterflies counted during sampling as the species abundance. Species richness estimates (non-parametric) were calculated on the basis of individual-based species accumulation curves (Gotelli & Colwell, 2001). Sampling effort and efficiency were estimated using the program EstimateS (Colwell, 2009). We calculated Fisher's alpha index (Fisher *et al.*, 1943) to compare the diversity of butterflies across three vegetation zones using the program Past 1.73 (Hammer *et al*., 2007). We performed cluster analysis using this program (Hammer *et al*., 2007) and produced a dendrogram showing the similarities in the composition of the butterfly community between transects. The analysis was based on a Bray–Curtis dissimilarity matrix (single link) of ecological distance.

RESULTS

BUTTERFLY SPECIES RICHNESS, ABUNDANCE AND DIVERSITY

With an effort of 43.5 km in 58 days in 8 months, we recorded a total of 1,639 butterfly individuals representing 34 species, 29 genera and five families in Gangotri NP during the study (Tables 1 & 2) (Plate II). The highest species richness, abundance and diversity were recorded in vegetation zone I, followed by zones II, III and IV. Interestingly, there were 16 species that were restricted to a single vegetation zone. They represent 47% of the total butterfly species richness recorded in Gangotri NP.

Table 1.

Species richness, abundance, diversity and number of unique species encountered in each vegetation category

Habitat	Number of transects (N = 29)	Species richness	Abundance	Fisher's *α*	Unique species
Zone I	8	22	802	12.4	10
Zone II	8	12	412	7.1	3
Zone III	5	9	233	8.3	1
Zone IV	8	5	192	2.5	2
Total	29	48	1639	30.3	16

Table 2. Butterflies documented along 29 transects in Gangotri NP in 2008

S.no	Common name	Species	Relative abundance
	Hesperiidae		
1	Indian Awlking	*Choaspes benjaminii* (Guerin-Meneville)	0.12

2	Common Snow Flat	*Tagiades litigosa* Moschler	0.06
	Papilionidae		
3	Common Blue Apollo	*Parnassius hardwickii* Gray	0.92
4	Common Red Apollo	*Parnassius epaphus* Oberthür	2.93
5	Common Yellow Swallowtail	*Papilio machaon* Linnaeus	2.38
	Pieridae		
6	Common Brimstone	*Gonopteryx rhamni* (Linnaeus)	5.67
7	Common Emigrant	*Catopsilia pomona* (Fabricius)	4.64
8	Dark Clouded Yellow	*Colias fieldii* Ménétriés	5.43
9	Large Cabbage White	*Pieris brassicae* (Linnaeus)	0.61
10	Indian Cabbage White	*Pieris canidia* (Sparrman)	11.96
11	Bath White	*Pontia daplidice* (Linnaeus)	2.32
12	Hill Jezebel	*Delias belladonna* (Fabricius)	0.06
	Lycaenidae		
13	Indian Purple Hairstreak	*Esakiozephyrus mandara* Doherti	0.06
14	Common Silverline	*Spindasis vulcanus* (Fabricius)	0.12
15	Common Copper	*Lycaena phlaeas* (Linnaeus)	2.07
16	Powder Green Sapphire	*Heliophorus tamu* (Kollar)	0.12
17	Sorrel Sapphire	*Heliophorus sena* Kollar	3.36
18	Common Hedge Blue	*Actyolepis puspa* (Horsefield)	7.57
19	Common Meadow Blue	*Polyommatus eros*	3.66
	Nymphalidae		
20	Common Beak	*Libythea lepita* Moore	0.12
21	Plain Tiger	*Danaus chrysippus* (Linnaeus)	1.95
22	Common Wall	*Lasiaommata schakra* Kollar	3.66
23	Common Satyr	*Aulocera swaha* (Kollar)	0.43
24	Yellow Argus	*Paralasa mani* De Nicéville	0.06
25	Highbrown Silverspot	*Fabriciana adippe* Denis and Schiffermüller	0.92
26	Queen of Spain Fritillary	*Issoria lathonia* (Linnaeus)	4.09
27	Common Sailor	*Neptis hylas* (Linnaeus)	0.12
28	Himalayan Sailor	*Neptis mahendra* Moore	2.87
29	Himalayan Jester	*Symbrenthia hypselis* (Godart)	0.06
30	Indian Red Admiral	*Vanessa indica* (Herbst)	8.66
31	Painted Lady	*Vanessa cardui* (Linnaeus)	11.53
32	Indian Tortoiseshell	*Aglais cashmiriensis* (Kollar)	10.25
33	Eastern Comma	*Polygonia egea* (Cramer)	0.06
34	Blue Admiral	*Kaniska canace* (Linnaeus)	1.16

INVENTORY COMPLETENESS

We calculated six estimators of species richness. The ACE and Chao1 estimates of species richness gave the largest estimates of species richness in Gangotri NP. These estimators are generally used for inventory completeness values and give the ratio between the observed and estimated richness (Sorenson *et al*., 2002; Scharff *et al*., 2003). Estimates of species richness produced by Chao1 are a function of singletons and doubletons and exceed the observed species richness by greater margins as the relative frequency of singletons and doubletons increases. Chao1 measures are especially sensitive to patchiness and were effective in cases where species were randomly distributed (Magurran, 2004). Using the ACE and Chao1 estimates (largest estimates) for inventory completeness, the species richness estimated during the current study was determined to be 77-80%.

PLATE II Some of the butterflies of Gangotri NP

Tagiades litigosa Möschler

Choaspes benjaminii (Guerin-Meneville)

Parnassius epaphus Oberthür

Papilio machaon (Linnaeus)

Heliophorus sena Kollar

Lycaena phlaeas (Linnaeus)

Delias belladonna (Fabricius)

Gonopteryx rhamni (Linnaeus)

Pieris canidia (Sparrman)

Danaus chrysippus (Linnaeus)

Issoria lathonia (Linnaeus)

Vanessa cardui (Linnaeus)

Aglais cashmiriensis (Kollar)

Vanessa indica (Herbst)

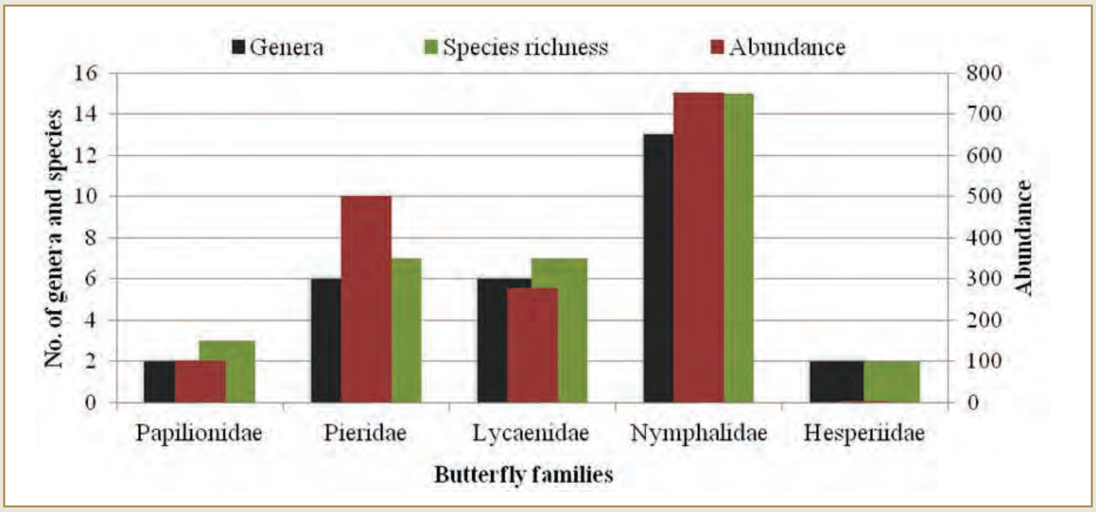
COMMUNITY COMPOSITION

The butterfly abundance ranges from 1 to 196 (Indian Cabbage White; *Pieris canidia*). The most dominant butterflies in the community were the Indian Cabbage White; *Pieris brassicae* (11.9%), Painted Lady; *Vanessa cardui* (11.5%), Indian Tortoiseshell; *Aglais cashmiriensis* (10.2%), Indian Red Admiral; *Vanessa indica* (8.6%) and Common Hedge Blue; *Actyolepis puspa* (7.5%) (Table 2). These five butterflies together account for 50% of the total butterfly abundance recorded. The community had six singletons (species that were recorded only once) and four doubletons (species that were recorded only twice). The community composition reveals that most of the butterflies were rare and restricted to a few vegetation and elevation zones only.

FAMILY COMPOSITION

We recorded five butterfly families, namely Hesperiidae, Papilionidae, Pieridae, Lycaenidae and Nymphalidae. The family Nymphalidae was the most dominant family and accounted for 753 individuals representing 15 species, followed by the Pieridae, Lycaenidae, Papilionidae and Hesperiidae (Fig. 2). We recorded a high genera richness, *viz*. 34 species belonging to 29 genera. The family Nymphalidae, represented by 15 genera, had the greatest number, followed by the Pieridae and Lycaenidae (both 6 genera) and Papilionidae and Hesperiidae.

Figure 2.

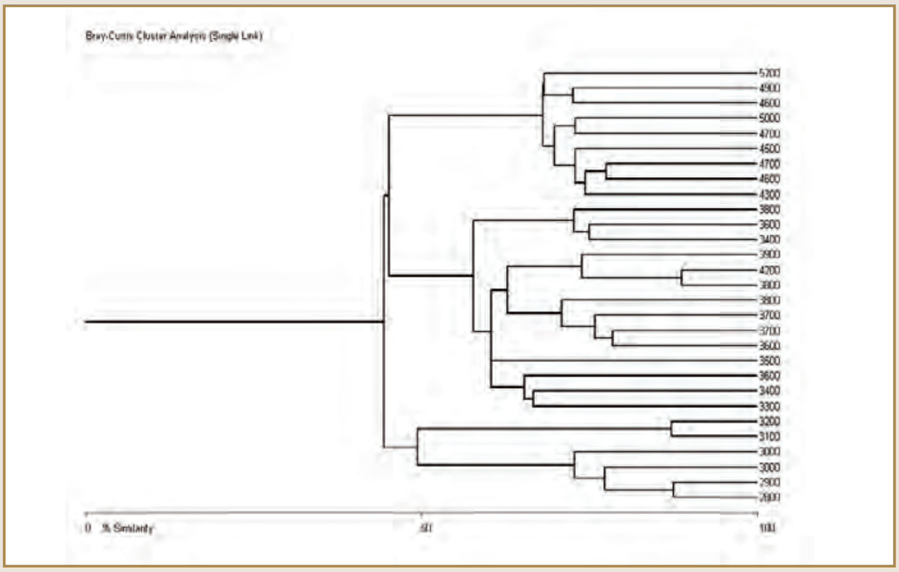


Genera, species richness and abundance of five butterfly families in Gangotri NP

SITE AND SPECIES SIMILARITY

The dendrogram obtained from cluster analysis of 29 transects in different elevation zones showed that the butterfly composition grouped into three major clusters (Fig. 3): (i) 2800-3200 m, (ii) 3300-3900 m and (iii) 4200-5200 m. Cluster analysis also revealed that the butterfly assemblages grouped into four sub-clusters. The results are consistent with elevation and vegetation zones. The high-altitude butterfly assemblage (4200-5200 m) was found in dry/moist alpine scrub habitat. The Himalayan moist temperate forest supports the unique butterfly assemblage found between 2800 and 3200 m.

Figure 3.



Dendrogram showing similarities between 29 elevational transects in Gangotri National Park (based on Bray-Curtis dissimilarity matrix—single link)

DISCUSSION

We were able to provide a reasonable estimate and sampled 77-80% of the butterfly fauna of Gangotri NP. We recommend sampling in all possible habitats and seasons to inventory the butterflies in the Himalayan landscape. It is extremely difficult to sample biodiversity in a given area as time and money are limited. Butterflies constitute a model system for large-sample, long-term monitoring studies to survey biodiversity quickly. To select and prioritize areas for biodiversity conservation, rapid assessments of biodiversity indicator taxa can be an important, helpful, quick and cost-effective tool for conservation managers.

There are approximately 417 species of butterfly in the western Himalaya (Wynter-Blyth, 1957). We would not expect to record a comparable number species at such a small site as Gangotri NP because it lacks representation from the lower elevations (500-2700 m), a major repository of species found in the western Himalaya. Gangotri NP holds a rich Himalayan biodiversity despite the fact that thousands of pilgrims visit Gangotri Valley during April-October each year, along with a large number of adventure tourists, who visit the area for trekking, camping, adventure activities and mountaineering and cause much harm to the Himalayan habitat and thus the biodiversity. Nilang Valley supports a different butterfly assemblage, similar to that of the Trans Himalayan region, which may be attributed to the fact that this area differs in its topography and vegetation composition from Gangotri Valley (which is siuated in the Great Himalayan ranges) as this valley resembles the Trans Himalayan region (an extension of the Zanskar ranges) more closely. The Nilang or Jadh Ganga Valley is an important habitat, but it is used by large herds of goats, sheeps and mules accompanied by herders from spring to autumn. An estimated 30,000 sheep, goats and mules graze these pastures intensively (Chandola *et al*., 2008). Nilang Valley is also exposed to military camps, disturbance activities such as livestock grazing and other development human activities (road construction for the military). Efforts are needed to check or minimise anthropogenic activities that lead to habitat degradation and fragmentation. Thus, management practices should be revised so as to give protection to these sites.

Very few studies have been carried out on the biogeographical distribution of the Himalayan butterfly fauna as many species have lost and extended their distribution ranges in the last 50 years. As the Himalayan forests are under severe threats of habitat degradation and forest fragmentation, there is an urgent need to carry out such studies on butterflies, especially for species that are endemic to the Himalayan region and its sub-regions. It is our expectation that the results presented and discussed here will help conservation planners and managers by aiding them in giving attention to the remaining fragmented habitats facing human alterations, which will intensify biodiversity conservation efforts in the area.

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CLIMATE CHANGE ADAPTATION AND HONEYBEES IN MOUNTAIN REGIONS

Harish K Sharma[1] **and Uma Partap**[2]

1. Department of Entomology and Apiculture, Dr. Y.S. Parmar University of Horticulture & Forestry, Nauni, Solan (H.P.) India
email : harishkulu@yahoo.co.in

2. International Centre for Integrated Mountain Development, Kathmandu, Nepal

The Indian Himalaya has been identified as one of the most sensitive landscapes and biodiversity hotspots undergoing unprecedented changes due to climate change and global warming. Changes in the mean climate and climate variability as well as extreme weather events are the direct effects of climate change. whereas changes in water availability and biological organisms are the indirect effects of climate change (Gornall *et al*., 2010). The UNFCCC (United Nations Framework Convention on Climate Change) highlights two fundamental response strategies to combat climate change, namely mitigation and adaptation. Adaptation calls for ensuring food security, enhancing livelihood opportunities and strengthening institutional systems. Some examples of adaptation of Himalayan ecosystems to climate change are listed below:

NATURAL SYSTEMS

- Changes in length of growing season
- Changes in ecosystem composition
- Wetland migration

HUMAN SYSTEMS

- Changes in farming practices

Mountain agriculture, involving food crops, livestock, fruits, vegetables, forests and honeybees, forms the main source of livelihood for local communities. Since honeybees and bee products are a source of direct income, nutrition and medicine for mountain farmers, beekeeping forms an important component of mountain agriculture.

The Asian honeybee *Apis cerana* is the domesticated honeybee species, which also exists in its natural habitat in different mountain states of India. There is an intricate relationship between plants and bees, which has existed since time immemorial and strengthened over time. Besides honey and other marketable bee products, the invaluable service of pollination provided by the bees enhances the productivity of agricultural and natural ecosystems and the diversity of flora in the Himalaya.

IMPACT OF CLIMATE CHANGE ON FLORAL DIVERSITY AND FARMING IN THE HIMALAYAN REGION

UPWARD SHIFT OF PLANT SPECIES

Many typical temperate species that were common earlier are now not traceable in their original locality. They are found either above their upper altitudinal limit or within a shrunken distribution. Important examples are *Aconitum heterophyllum* and *Lilium polythyllum*, found earlier in and around Shimla, which have now moved towards higher elevations and are found 600–800 m above their original altitudinal range (Rana, 2010).

FLOWERING PATTERN

Increasing temperatures have resulted in a change in the flowering pattern and time of flowering of many plants. Erratic and decreased rainfall also has a direct impact on flowering and on nectar secretion in the flowers of the flora at a particular time. Many plant species are also responding to climate change by advancing the onset of leaf burst, flowering and fruiting, delaying leaf drop and flowering in insect-pollinated plants earlier than wind-pollinated plants (Fitter and Fitter, 2002; Menzel and Fabian, 1989; Menzel, 2000). For example, Rhododendron is also reported to have flowered in early February in 2009, as opposed to early to mid-March as it used to do in previous years in and around Shimla, Himachal Pradesh (Rana, 2010).

SHIFTING CROPPING PATTERNS

Today's cropping pattern clearly indicates that fruit trees, vegetables and agricultural crops at the lower altitudes in mountai ous regions are most affected by the change in climate. Farming areas previously suitable for apple cultivation (1200-1300 m amsl) have shifted from apple to vegetable production and other fruits such as pomegranate and kiwi in Himachal and citrus in Uttrakhand (Bhatt, 2010); apples have moved to higher-altitude areas. The higher-altitude areas, where farmers used to grow traditional agricultural crops such as buckwheat, barley, finger millet, grain and amaranth have now become more suitable for cultivation of crops such as apple, potato, garden pea and other off-season vegetables and medicinal plants that fetch higher prices (Sharma & Rana, 2005). As a result, in these areas, traditional farming of food crops has now been replaced with cash crop farming.

STATUS OF *APIS CERANA* BEEKEEPING

Apis cerana beekeeping is a part of the cultural and natural heritage of several mountain communities. Studies carried out by the International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, reveal that *A. cerana* can be divided into three subspecies, namely *A. c. cerana, A. c. himalaya* and *A. c. indica*. *A. c. cerana* is distributed throughout the north-western Himalayan region of India. *A. c. indica* is found in the plains and foothills of the region. Beekeeping in India dates back to 1470 AD. The first modern apiary using *A. cerana* was established in Kashmir in 1930 at Srinagar (Abrol, 2001) and in 1934 in Kullu Valley (Sharma *et al*., 2000). Modern beekeeping gradually developed thereafter. By 1984-85, there were 40,000 *A. cerana* colonies producing 600 tonnes of honey in Kashmir (Abrol, 2001). The average honey yield per colony ranged between 10 and 12 kg in Kashmir and between 4 and 6 kg elsewhere in the country.

Larger proportion of *A. cerana* colonies is still domesticated in traditional hives. Assam has leading position with 5 million colonies of *A. cerana* followed by Manipur, Meghalaya and Tripura (Rahman, 2011). In Himachal Pradesh only 400 colonies are reared in modern hives and few thousands are still reared in traditional hives (Rana *et al*., 2011). Uttarakhand has about 54,000 colonies of *A. cerana* being domesticated in modern and traditional hives (Personnel communication with State Apiarist, Government Beekeeping Centre, Jeolikot, Nainital). Besides *A. cerana*, migratory beekeeping with exotic honeybee *Apis mellifera* has also been introduced in northwestern and central Himalaya.

The north-eastern region (NER) consists of the eight states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim. These states have a moderate climate. At an estimate, 1.85 lakh bee colonies are maintained by about 25,000 beekeepers, producing about 800 million tonnes of honey (Singh, 2006). As in the western and central Himalayan mountain states, bees in the north-eastern Himalayan states are maintained in traditional log, basket or wall hives. *A. cerana* beekeeping was affected a lot due to the Thai Sac Brood Virus (TSBV) disease. Thereafter, *A. mellifera* was introduced in the region. However, *A. cerana* colonies have now recovered from this deadly disease. Beekeepers are also practicing scientific beekeeping using movable frame hives. According to one report from Himachal Pradesh, the negative impacts of various biotic and abiotic stresses has resulted in a reduction in the bee colony population of up to 100 per cent during the decade, as in Chamba, Himachal Pradesh.

ISSUES OF CONCERN

Mountain areas are characterized by inaccessibility, fragility, marginality, diversity, niches and adaptation mechanisms. The indigenous beekeeping system fits well with these characteristics and supports the livelihood of mountain people. There is a need to develop beekeeping on scientific lines to give an impetus to the beekeeping industry in the mountains.

Some of the important issues in mountain beekeeping with respect to the environment are discussed in the following steps.

LONG WINTER

The main constraint in the development of the beekeeping industry in mountainous regions is the long winter. During the long winter months, honeybees require special care and management. Besides, *A. mellifera* beekeeping on a commercial scale becomes unprofitable if not migrated to low hill areas/plains or if it is not managed well.

EXCESSIVE USE OF PESTICIDES

Beekeeping and pesticides are both essential inputs for today's agriculture. Therefore, ignoring either will have a direct impact on food production. But an indiscriminate use of pesticides is seriously affecting the natural pollination (including honeybees) population, which is ultimately affecting pollination process in food crops and forest plantations. There is a need to promote safe and judicious use of pesticides in agriculture in order to protect bees as well as human health.

DEFORESTATION: DEVELOPMENT IN HILLY STATES IS AT THE COST OF DEFORESTATION

It has been estimated that there are 25-50 different forms of life dependent upon each plant. When key plants die out of an eco-system, that system goes into a decline, and dozens of other forms in that eco-system also disappear or get affected. The destruction of the homes of both honeybees and non-honeybee pollinators can be attributed to modern farming methods.

HONEYBEES AND THE FLOWERS THEY FEED ON ARE BEING STUNG BY CLIMATE CHANGE

Climate change is decoupling species that interact. Plants may be getting decoupled from insect attack or from insects that serve them, such as pollinators. Even pollinators, including honeybees, get decoupled from important flowering plants that provide nectar and pollen to them. The recent declines in the numbers of bees and other pollinators worldwide (evident from Tables 1 & 2, Mattu, 2010) are also a cause for concern. The change in flowering pattern has happened over a 20-30 year time frame. Bees are capable of evolving so that their emergence coincides with the flowering, although they will probably lag for a few years.

Table 1. Population decline of honeybees in the world

Country	Decline (%)	Duration
Germany	57	Last 15 years
U.K.	61	Last 10 years
U.S.A.	>50	Last 20 years
Poland	>35	Last 15 years
India	>40	Last 25 years
Brazil	>53	Last 15 years
Netherlands	58-65	Last 25 years
China	>50	Last 20 years

Table 2. Decline of pollinators in the U.S.A.

Pollinators	Loss in population (%)
Honey bees	>50
Bumble bees	36
Solitary bees	30
Bats	14
Humming birds	16
Monarch butterflies	28

RISING TEMPERATURES

Rising temperatures lead to less precipitation in the form of snow. This in turn will influence the discharge of water in the pre-monsoon period. More floods and landslides can be expected in mountainous regions. Less water in the pre-monsoon period will affect the availability of water for irrigation and will affect food security. Increased temperatures also have a direct impact on the floral rewards (nectar and pollen) from the available bloom. This will affect the sustainability of apiculture in an area.

CHANGES IN PRECIPITATION TRENDS

The changing precipitation pattern shows an increasing number of dry days and higher concentrations of rainy days. This condition also has a direct impact on the floral rewards at a particular time of the year.

WAY FORWARD

AWARENESS RAISING

Honeybees and pollinators play a great role in enhancing incomes and improving the food security of mountain populations through provisioning and ecosystem services. There is a need to enhance knowledge and understanding about the role of honeybees in food production and human nutrition for sustainable development of mountains and providing better livelihood opportunities to mountain people. Thus the general public and policy makers need to be sensitized about the role played by insect pollinators, including honeybees, in pollination in order to protect and conserve them. There is an urgent need for creating awareness at all levels about the important services that indigenous honeybees are providing to the ecosystem and the livelihood opportunities that they are providing to the mountain community.

BEEKEEPING AS AN INTEGRAL PART OF MOUNTAIN FARMING

There is a need to develop the mountain beekeeping industry, which has its own potential and problems. Honeybees have been reported to be important for sustaining many plants and plant communities, and most wildlife is dependent upon both. Keeping in view the important role of honeybees and their biological significance as important pollinators of agricultural crops, honeybees and pollination activities should be made an integral part of mountain farm management technology.

INCLUSION OF BEE FORAGE IN VARIOUS PLANTATION PROGRAMMES

When planning an agro-forestry, watershed development or any other afforestation programme, various forage plants for pollinators, especially honeybees, should be taken into consideration. This will be quite helpful in sustaining honeybees, especially under the changing climate scenario.

SAFE USE OF PESTICIDES

Integrated pest management should also be promoted so that pesticidal sprays can be reduced or minimized. Farmers should be educated not to spray insecticides on blooming crops. If at all necessary, all precautions should be taken. Special care should be taken not to contaminate water sources as bees require water to cool their hives and feed the brood.

DIVERSIFICATION OF HABITATS FOR BEES AND POLLINATORS

Efforts should be made to sustain the pollinator diversity in agro and natural eco-systems. Diversified wildlife landscaping rather than monoculture cultivation should be encouraged to provide floral resources for pollinators.

STOCK IMPROVEMENT

In the case of *A. cerana,* traditional beekeeping should be encouraged. To encourage more beekeepers to adopt movable frame *A. cerana* beekeeping there is need to improve it—both the 'honeybee' itself and management practices in *A. cerana* beekeeping. Our studies on selective breeding of *A. cerana* have revealed that there is a great variation in the performance of different colonies in terms of honey production, disease resistance, etc. Thus there is great scope for improvement.

RESEARCH ON APIARY MANAGEMENT

During the course of evolution, *A. cerana* has developed certain behavioural traits that seem to be essential to the survival strategy of this bee species but are undesirable from a beekeeper's point of view. Adoption of better management practices is likely to avoid such problems. However, there is also a need for research on apiary management methods. Besides, standard quality equipment for domestication of *A. cerana* needs to be made available.

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CONSERVATION OF SPIDERS IN INDIA

Ganesh Nanu Vankhede

Department of Zoology, Sant Gadge Baba Amravati University, Amravati-444602
email : vganeshan2001@rediffmail.com

INTRODUCTION

For many decades, insecticides have been widely used to control pests in all natural habitats and in urban ecosystems. However, the continuous use of a wide range of pesticides has caused many side effects, including loss of biodiversity. The loss of spider diversity is no exception. The situation is worsening due to climate change, global warming and global dimming. Changes in traditional agricultural practices, increasing incidences of forest fires, excessive grazing activities in forests and urbanization have intensified the loss of biodiversity. In such a situation of unstable seasons and depleting sources of water, environmentalists and arachnologists have to think of conserving important species such as spiders as they are the only species that keep ecosystems in balance in all respects.

Spiders are potential biocontrol agents because they are relatively resistant to starvation and desiccation. Additionally, spiders become active as soon as conditions are favourable, and they are among the first predators able to limit pests. The risks associated with using spiders to control pests are minimal. They do not harm plants. Since diverse species of spiders are naturally present in all ecosystems and are predaceous at all stages of their development, they occupy many niches, attacking many pest species simultaneously. If we can conserve these species, we can save biodiversity, ecosystems and our gene pool as well. It will be a win-win situation.

Up until 2005, most of the research on Indian spiders was concentrated on identification (Biswas, 1975; 1984;Gajbe,1979; 2008; Patel, 1973; Patel and Raghavendra, 2001; Sebastian and Peter, 2009; Tikader, 1960; 1987). After 2005, apart from listing spiders, researchers began to study their basic ecological and biological characteristics as biological control agents (Uniyal, 2006; Hore and Uniyal, 2009). But now, it has become necessary to find solutions for conserving the depleting populations of spiders in the light of climate change. The most important reason for conserving spiders is the role they play in providing free ecosystem services, such as keeping in control insect pest populations, serving as food for birds and bees, and provision of spider silk and venom.

In India, spider populations are decreasing rapidly because of the following threats: (1) climate change, (2) grazing, (3) deforestation/habitat loss, (4) forest fires, (5) scarcity of water, (6) use of pesticides in agriculture, (7) Indian agricultural practices such as burning of litter and waste of crop remains and ploughing during late May, (8) use of mosquito repellents and larvicidal pesticides to control malaria, (9) urbanization, (10) development of road networks and (11) trade.

CLIMATE CHANGE IS PROVED TO BE THE PRIMARY THREAT TO SPIDERS

Due to climate change, the seasons have become unstable. There can be rains in summer or even in winter. Most spiders require the right humidity for survival, and their life cycles are synchronised with the rainy season and winter. Most spiders lay egg sacs during September/October *i.e*. by the end of the rainy season. If there are heavy rains during winter or if there is global dimming, there is high mortality. Because of global warming, there is water scarcity, resulting in a less hygroscopic environment, and spiders cannot tolerate high temperatures. Streams become dry, and there is no water in downstream reservoirs. These conditions are unfavourable for the survival of spiders. The structural complexity of the environment is directly related to the spider density and diversity.

GRAZING BY DOMESTICATED HERBIVORES AS A THREAT

Grazing by domesticated herbivores in forests leads to destruction of the habitat of spiders that inhabit grasses and shrubs, for example *Argiopes* (Signature Spider). During grazing, some spiders are eaten up, and in many cases the orb web is destroyed and the spiders have to spend more energy for preparing another web. Grazing also results in loosening of soil on the slopes, thus leading to soil removal during the rainy season as runoff. This affects the growth of shrubs (habitat degradation), affecting the spider population. Grazing also results in the spread of *Lantana camara* (a weed), which prevents the growth of shrubs and grasses, affecting the spider habitat severely. In India most forest habitats are facing the problem of this weed suppressing the growth of endemic shrubs and grasses. To conserve spiders, grazing by domestic herbivores must be avoided in forest management plans to protect spider habitats.

DEFORESTATION/HABITAT LOSS

Deforestation destroys many natural habitats, affecting the natural composition of animal and plant communities. When forests are just cut down and natural succession is allowed to take place, a different flora and fauna colonize the area, affecting the spider diversity and population.

In addition, the soil is destroyed when the organic litter of the forest floor is washed away. There are a lot of different weeds that grow quickly in clear-cuttings after logging and/or burning, and the vegetation is altered within a short period of time. The weeds create new habitats for many different kinds of arthropods. But spiders require suitable places to make their webs.They take time to adjust to the new conditions, and the population is affected.

There is a loss of the habitat of *Thrigmopoeus truculentus* in the Western Ghats. This spider is categorized as 'Near Threatened' as it does not meet the 'restricted distribution criteria'. The habitat of *Poecilotheria hanumavilasumica* (Rameshwaram Parachute Spider) has been destroyed because of various reasons and due to the limited area of distribution of this spider, its existence is in peril. It is declared as Critically Endangered. Hence, if we learn about such microscopic details of every species, we will be able to save them from extinction.

There is a need to seriously look into the taxonomic details, descriptions and assessments of the distribution of the tarantula group. We need to identify new tarantula species, understand their distributions and identify the threats associated with their existence. Only then can we conserve them.

FOREST FIRE AFFECTS SPIDER DIVERSITY AND POPULATION: MELGHAT - A CASE STUDY

Forest fires have a profound effect on all arthropods in a forest ecosystem. Not only does the burning kill a lot of arthropods directly, it also alters the ground vegetation and the organic soil cover, which in turn alters the conditions for ground-living animals. In one experiment, we studied the spider population before and after a forest fire. We also studied the impact of the forest fire on the soil pH and the population of spiders in the following season. In a dry deciduous forest, the plant litter starts decaying after the first rains and forms a suitable habitat for soil arthropods and bacteria, which helps complete the decaying of the litter. Spiders feed on this arthropod population, controlling them. The excreta of the spiders fall on the soil, affecting its pH. Thus in a food web, spiders play a crucial role as predators and are at the top of this temporary ecosystem. Then in the following months, grasses and shrubs develop, providing a good habitat for other spiders. We found less diversity and a smaller population of spiders in Melghat in fire-affected compartments.

To conserve spiders, fire can be prevented by carrying out fire line work well before February.

SCARCITY OF WATER

Spiders from the families Pisauridae and Tetragnathidae prefer to live along streams and water bodies. If water is not available during their life-cycle stages, from the laying of egg sacs to development up to eight or nine moulting stages, they cannot survive.

To conserve these spiders, water must be made available by digging trenches in streams before the rainy season so that water will be available and maintain the correct humidity. During these days of global warming, the population and diversity of pissaurids are affected. From data for the last 5 years from India, it is clearly seen that no new species have been added from these families and that their population is decreasing in Melghat, Maharashtra.

USE OF PESTICIDES IN AGRO-ECOSYSTEMS

Farmers use pesticides to protect their cash crops from pests. They spray pesticides to kill the pests, and simultaneously, non-target invertebrates such as spiders are also killed. Actually, spiders being generalized feeders, can feed on a variety of pests and protect the crops, but farmers use pesticides that kill the spiders too. Several applications of pesticides per season can destroy spider communities. Some pesticides are also retained in the webs of spiders and can be detrimental to those spiders that ingest their webs daily. Pests come back and attack the crop, but spiders do not return so easily to the fields. This creates an imbalance, and the farmers are at a loss.

The ecological and biological characteristics of spiders need to be understood. It takes longer for the population densities of spiders to build up after the application of insecticides compared with plant hoppers and leaf hoppers because spiders have a longer generation interval.

To conserve spiders, the use of pesticides must be banned and farmers should be trained about this. Even spiders can be used as biocontrol agents. Yes, it is possible if spiders are reared according to the infestation of crops. Fortunately, the life cycle of agriculture cash crops overlaps with the life cycle of spiders, *i.e.* June to December. Farmers can be trained for rearing spiders that have high fecundity.

INDIAN AGRICULTURAL PRACTICES

BURNING OF LITTER AND WASTE OF CROPS, PLOUGHING DURING LATE MAY

In India, agricultural practices are changing, and farmers have stopped using organic fertilizers. In one experiment, we saw that banana fields in which organic manure was used had quite a high spider population (780 Thelacantha per acre + 1240 Cyclosa per acre + 2000 lycosids + other spiders) compared with that in an agrofield in which inorganic fertilizers were used. The family Lycosidae made up only 5% of the community in conventional fields where inorganic pesticides were used, but they made up 35% in organic fields. Spider densities were also found to be increased in banana and orange fields where straw mulch was used as a ground cover to prevent water evaporation. Burning litter and crop remains kills ground spiders. To conserve ground burrowing spiders in agro-ecosystems, farmers should plough their fields before March so that these spiders are not destroyed because their burrowing activities begin during the first week of April. They grow and mature before the onset of the rainy season. Soil disturbance by ploughing destroys overwintering sites and can kill any spiders already present in the soil. The movement of farm equipment through a crop field damages spider webs and may destroy web attachment sites. Consequently, the spider density and diversity are higher in organic fields than in conventional ones. Spiders have a wide range of prey species, catch significant numbers of their prey and use various foraging strategies. Crop diversity also leads to an availability of alternative prey, which may increase the spider diversity as well as reduce the territory size of spiders, leading to a stable population of spiders at high densities. Conservation of predators like spiders in the field can be accomplished by reducing physical disturbances to the habitat. Thus, to conserve and enhance spider populations, agricultural systems should be manipulated in ways beneficial to the needs of spiders.

USE OF MOSQUITO REPELLENTS AND LARVICIDAL PESTICIDES TO CONTROL MALARIA: A THREAT FOR SPIDERS

For mosquito control, Indians use mosquito repellents in their houses. This has badly affected the population of house spiders such as *Pholcus*, Salticids and Gnaphosids. Spiders in houses are helpful in mosquito control. A room of size 10 feet × 10 feet must have five or six pholcids if all the mosquitoes are to be fed on. Similarly, the larval stages of mosquitoes that inhabit water bodies can also be controlled by spiders such as tetragnathids, pisaurids and lycosids, living along ditches, streams and rivers. However, we spray pesticides or phenyls to kill the larval stages. Spiders can feed on adult mosquitoes as well as on the larval stages of all types of mosquitoes.

Hence, spiders can be conserved by discontinuing the use of mosquito repellents and pesticide sprays.

URBANIZATION

Urbanization is nothing but habitat fragmentation, destruction and/or habitat conversion. Mostly agriculture land or forest land is used for urbanization. This leads to low diversities and higher abundances of restricted species. Particularly, spiders from the families Pisauridae, Tetragnathidae and Clubionidae lose their habitats. Spiders from the families Salticidae, Linopidae, Pholcidae, Oonopidae and Araneidae dominate urban habitats. To conserve spiders from the families Pisauridae, Tetragnathidae and Clubionidae, which have lost their habitats, development of kitchen gardens, establishment of parks in colonies with moving water in gutters and plantation of trees can be practiced. The FSI of constructions should be increased, with buildings growing vertically rather than horizontally.

DEVELOPMENT OF ROAD NETWORK

India being a developing country, development of the road network in India is unavoidable at present. Tree felling is carried out to widen existing roads. This destroys the habitats of spiders that inhabit tree trunks, *e.g.* spiders from the family Hersiliidae, a few spider salticid genera such as *Marengo* and *Myrmarachnae* and social spiders from the family Eresidae. The list is very long. Even in forests, after the rainy season, utility roads are repaired by cutting grasses growing on old roads. This practice should be prolonged till the end of December so that the spiders using grasses develop completely and are dispersed widely. Otherwise, after a prolonged period of wrong practices, these species will become endangered. At present most of the spiders are classified as Data Deficient, and research is needed.

For conservation of these spiders, it is suggested here that, before felling of trees for developing the road network, trees be planted first at the necessary distance. Once these grow, the old trees can be cut for new roads.

TRADE

Species such as tarantulas are collected and killed on a large scale. Some of the species such as Black Widows are collected for venom in India, and hence their population is decreasing. Tarantulas, the creepy and crawly spiders, are in great demand the world over. And there is apprehension in the Western Ghats, where the species is dwindling because of a sudden aggressiveness in the illegal trade in these arachnids. The poaching of spiders goes unnoticed, and there is no movement as such against the trade. The International Union for Conservation of Nature has listed *Poecilotheria regalis, Poecilotheria striata, Poecilotheria hanumavilasumica, Poecilotheria miranda* and *Poecilotheria metallica* in the Red Data book as threatened with extinction. *Thrigmopoeus truculentus* is categorized as 'Near Threatened' because it does not meet the restricted distribution criteria. Of the 90 tarantula species found in India, there is a huge demand for 62 for ornamental purposes. These mygalomorphs should be brought into the scheduled group under the Wildlife Protection Act so that they can be conserved.

SPIDERS HELP IN WATER PERCOLATION IN AGRO-ECOSYSTEMS

Various tarantulas and *Geolycosa* (Lycosidae) spiders make holes in the soil during the summer and rainy season, helping water percolation. According to one estimate, there are more than 300 holes made by *Geolycosa* per acre. This definitely helps the percolation of water in the soil, increasing the water-holding capacity of the soil.

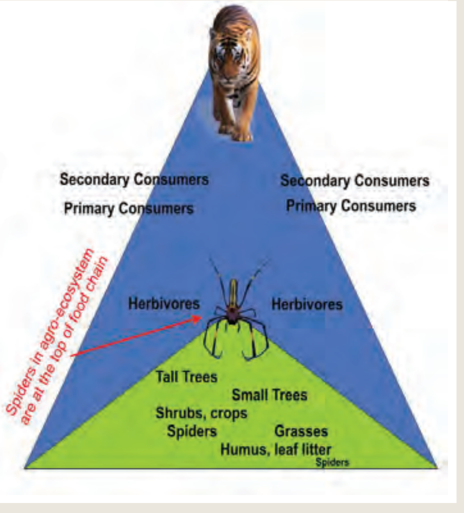
Figure 1.

Hole made by Geolycosa in agricultural field

TO SAVE TIGERS, CONSERVE SPIDERS

After the rainy season, shrubs and grasses grown on the pH-corrected (by spiders) soil on which most of the herbivores (primary consumers) depend. The primary consumers (carnivores), the secondary consumers (carnivores) and ultimately the umbrella species, the Tiger also depend on the pH-corrected soil. Thus, if there were no spiders at the bottom subset of the ecosystem, Tigers would not get enough food to survive. Here, it is important to say that the ecosystem in which spiders live is a subset of the ecosystem in which Tigers live. So if spiders are conserved, Tigers are automatically conserved.

Figure 2.



Diagramatic representation showing spider ecosystem as a subset of Tiger ecosystem

CAN WE REALLY CONSERVE SPIDERS?

As many as 43678 spider species are known in the world (Platnick, 2012), and in India, 1685 spider species from 438 genera have been reported till date (Keswani *et al.*, 2012). The problem is that very little work has been carried out on the behaviour and life cycles of all these species. Specific habitats have also not been reported for many species. Rearing techniques are under trial. Climate change has stressed the fauna and flora, and unless the atmospheric CO_2 concentration is kept below 350 ppm, the problem cannot be solved. If we see past natural history, 251 million years ago (Permian-Triassic period) a mass extinction occurred on earth due to the carbon dioxide level becoming as high as 2000 ppm, which eliminated 90% of the ocean dwellers and 70% of land plants and animals. Because of global warming 120 million years ago, during which carbon dioxide levels reached 550–590 ppm, another mass extinction involving 80–90% of the marine species and 85% of the land species, including the dinosaurs, was evidenced before 65.5 million years ago.

However, in this gloomy scenario in India, there is still hope that spiders can be conserved by making students, researchers and people aware about this most urgent issue, which can be solved not only by keeping the atmospheric CO_2 concentration below 350 ppm but also by maintaining the ecosystems of spiders lively and healthy. In my opinion, the primary cause of the decline of spider diversity is not direct human overexploitation but habitat destruction. Arachnologists should study the life history strategies and sensitivity of spiders to changing habitats. At present most of the spider species in India are classified as Data Deficient. The forest, irrigation and agriculture departments should work collectively to solve the problem of conservation of spiders by preventing fire, providing enough water for healthy ecosystems and following ecofriendly agro and forest practices. Farmers in particular must stop using fertilizers and pesticides and go for organic farming, using integrated pest management.

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CHALLENGES FOR TAXONOMY IN INDIAN CONTEXT

H.V. Ghate
Modern College, Pune.
email : hemantghate@gmail.com

ABSTRACT
Indian biodiversity is in crisis due to large-scale habitat modification. Current inventories of biodiversity, especially of insects, are going at a snail's pace. Of the many reasons why taxonomical work is slow, non-availability of comparable specimens and museums, lack of older important literature, lack of a network of taxonomists, less emphasis on modern tools of taxonomical research, a near-absence of training in taxonomy at the undergraduate and post-graduate levels, are just a few. I am thinking aloud as to what can possibly be done to at least alleviate the problems of taxonomical work, and that is the theme of this paper. My personal opinion is that these problems can be treated as challenges by our taxonomists and that we should respond with a unified team effort. We have a lot to build still on the fantastic base provided by the Fauna of British India volumes. We must not be complacent as much of our land and waters are unexplored for diversity, and we certainly have many surprises in store. We must enthuse and encourage young zoologists to make a career in taxonomical studies. We must work together in larger groups, collaborate with bioinformatics people, use all available modern tools, enter cyberspace truly and make our discipline a web-taxonomy. Without recourse to these techniques, we will stagnate and put ourselves at a great disadvantage vis-à-vis taxonomists of developed countries. Besides, our biodiversity studies will get on very slowly, our conservations efforts will suffer, and we may lose some of our biodiversity components before those are fully understood. Current biodiversity inventories and environmental impact assessments are not done with full understanding of taxonomy, and in most case, taxonomists are not involved at all. Let it be firmly stated that conservation programs need to know the organism in question and that is the job of a taxonomist.

INTRODUCTION
"Without taxonomy to give shape to the bricks, and systematics to tell us how to put them together, the house of biological science is a meaningless jumble." May (1990)

"No science can contribute more to our knowledge of evolutionary history (of organisms) or biodiversity or to human or environmental welfare than taxonomy; no science stands to lose more from biodiversity crisis than taxonomy" Wheeler (2008 b)

India is a vast country with many different, climatically distinct, regions. We have very cool and very hot regions, evergreen as well as shrub vegetation, rain-rich areas in the North-east and an arid desert in the west. It is but natural that we have a diverse fauna and flora and that we are recognized as a biodiversity-rich country. It is, in fact, one of the 17 mega-diversity countries of the world. We have many of the so-called biodiversity hotspots, the Western and Eastern Ghats, the Himalaya, and North-east India, being a few of these.

We are also fortunate in having quite a significant portion of our biodiversity already well explored and documented both vertebrates and invertebrates. A series of volumes, "Fauna of British India", written in the times of British occupation and published during 1890–1945, document this diversity in the traditional scientific manner. In fact, very few countries can boast of having such a splendid documentation of biodiversity. Thus the taxonomy of vertebrates such as fishes, amphibians, reptiles and mammals and invertebrates such as freshwater sponges and hydroids, butterflies and moths, beetles of the families Cassidinae and Cerambycidae, odonates and molluscs, to name a few, was studied in considerable detail prior to the 1950s. All these "Fauna" volumes were published by Taylor and Francis, London, and are now freely available as PDF files on the Internet, and hence their details are not given here. The basic work was thus done for most groups; yet, taxonomical work in the post-independence era has been very slow. Notable volumes have been produced in the Fauna of India series, and even region-wise faunas are being published by the Zoological Survey of India (ZSI). Some people are also publishing checklists independently, but checklists have limited uses as there is no authenticity, no locality or distribution data, no illustrations, *etc*. This is not true in India alone; the decline in taxonomical work and reduction in the number of taxonomists is a global phenomenon. Today most biodiversity-rich countries face a shortage of taxonomists, while there is an abundance of taxonomists in biodiversity-poor areas. MacLeod (2008) has already said that "taxonomic experts in all but the most charismatic groups are in danger of becoming as rare as some of the species they study".

Among the invertebrates, the insects are undoubtedly the most diverse group, with just one order, Coleoptera, having more than 3,75,000 species. We have an abundance of species of the orders Lepidoptera, Diptera, Odonata, *etc*. However, taxonomists dealing with these groups in India are very few. Even the Zoological Survey of India (ZSI), Government of India, the official body to document biodiversity, has very few taxonomists, and for many orders / families of insects there are none as many senior taxonomists have retired. The official website of ZSI recently stated that there are over 2 million specimens in their collection that are yet to be determined. As far as universities and other institutions are concerned, the situation is even worse. Taxonomy and systematics are not taught with sufficient depth and expertise at undergraduate or post-graduate courses, and so the recruitment of young taxonomists is going to be very hard task in the decades to come. Taxonomical work has been considered as 'inferior or descriptive' work compared with modern or 'experimental' science. Some do not even treat taxonomy as a scientific discipline. This situation and many problems faced by taxonomists have been discussed in detail by several authors in a single influential book, The New Taxonomy published by Systematic Association (Wheeler, 2008a), UK.

With the current rate of habitat destruction due to urbanization and pollution, brought about largely due to the rapid growth in the human population, all forms of wildlife are in peril. There is a certain biodiversity crisis, and the generations to follow will be lucky if they see half of what we have today. How to conserve these life forms is the greatest of worries. Unfortunately most people do not understand that taxonomical work is the basis of all biological work and that conservation of any living form will not be possible without knowing those forms taxonomically. We cannot try to protect what we do not know. Even for insects we must know their identity well, their life cycles and their food and habitat requirements. It is here that taxonomists and field biologists (naturalists) can contribute significantly. Apart from conservation issues, the identity of a plant or animal is the priority in any biological research of an applied nature. Is it possible to obtain a drug from a plant and to test other similar plants without their taxonomic identity? Can biotechnology survive without basic work done by taxonomists? Can genomics or proteomics data be useful or interpreted well without knowing the identity of the organism in question? Simply emphasizing applied courses at the college or university level has created serious problems, and taxonomy is ignored. Already we are far behind in applying novel technology and techniques in taxonomy and are still struggling with alpha taxonomy when people abroad are revising tribes, genera and families and are busy preparing monographs and are simultaneously testing earlier hypotheses on phylogeny in the light of modern techniques.

INSECT TAXONOMY

WHAT IS POSSIBLE IN INDIA?

In India we should now seriously take some active steps to rejuvenate taxonomy, especially insect taxonomy. This can be done in many ways, and in my opinion the following are some of the things we can attempt.

There are few taxonomists working on insects. With my own experience I can say that for groups such as the Mantodea, the Cassidinae and Cerambycidae beetles and the Pentatomorpha bugs, there is not a single worker in the entire state of Maharashtra and perhaps not more than two to five at the all-India level. To improve this situation, all universities must take active steps in organizing "true hands-on-training workshops" and try to train at least 5-10 good students every year who will pursue taxonomical work on one group in that university. Universities can certainly allot funds and get additional funding from the UGC to do that. The Zoological Survey of India used to hold such workshops, a tradition that was lost for many years and has been revived in 2012 with a recent workshop at Calicut. Some students must be provided funds to visit internationally reputed museums where taxonomists are active and where there are many specimens (including type material important for us) to study. For many groups that are not studied in India, training for a period of 1–2 years in a foreign country is absolutely necessary, and the amount spent on this must be treated as an investment. At present, such Indian–foreign projects are mutually run, but for biotechnological purposes; so similar projects must be floated for taxonomy. These workshops must also give a detailed explanation of ICZN rules, as people seem to be unaware of these rules. In addition, some students must be provided funds to visit internationally reputed museums where taxonomists are very active and where there are many specimens (including type material important for us) to study. For many groups that are not studied in India, training for a period of one to two years in foreign museum / country is absolutely necessary and the amount spent on this must be treated as an investment. At present similar Indo-Foreign projects are mutually run but for biotechnological and other purposes; so similar projects for taxonomy are not impossible and must be floated as the mechanism is established for such collaborations. Expert taxonomists from all over the world can be invited to contribute to such workshops through such collaborations and I am sure it will be immensely beneficial. PhD problems involving one Indian and one foreign expert taxonomist as supervisors will be another way. CSIR-UGC Fellows also can be encouraged to spend a short term with foreign experts and learn taxonomy of a particular group in depth.

There is another, and serious, need for museums where collections of insects (and other animals) are preserved and maintained meticulously for years. We all quote the Western Ghats as a biodiversity hotspot, but do we have even a single museum where the entire known biodiversity of even one group of animals is displayed for the public or is available for scientists? Good taxonomy is impossible without lot of comparative material. Besides, the public must also know the components of our biodiversity and pay to enrich that. Why taxonomical work is in the forefront in countries such as the USA, Germany and other European countries is that they have invaluable collections in their large museums. These collections are available to genuine workers from any part of the world. Many of these European museums still hold type material of great significance to researchers in India. It is time we created good museums for taxonomy to survive. These museums must contain authenticated material with valid current names. Again, we can entrust universities to erect such museums. At present many students catch insects for the routine work of the semester, and their entire collection is destroyed at the end of their semester. Most of these insects are not even identified correctly! If even a part of this is preserved for posterity in museums, it will be very useful. Trained personnel must be employed to mount and curate specimens, but for lack of these, taxonomists have to learn and do this work themselves. All authenticated material must be properly registered and all relevant information with images must be digitized and made freely available to all.

These museums must now be state-of-the-art museums with ultra-modern equipment (not what most common people call warehouses), almost like a 'glamorous' biotechnology lab'. As we shall see later, newer technologies are essential for rapid communication/exchange of digital data between taxonomists. The museums should be equipped with high-quality stereo-zoom microscopes, dedicated digital cameras, stacking software, good computers with image processing software, Internet connectivity with a high-speed Internet line—all these are absolutely essential. Taxonomists must become computer savvy (and be able to handle photography, image processing, Internet applications, *etc*.) or collaborate with those who can (bioinformatics people). In a few days' time we will be able to chat with a taxonomist in Europe and simultaneously see actually the specimen he/she is handling under the microscope, ask questions and settle the identity of our specimen … all this sitting in our own lab! The reverse should also become possible: you can show your specimen directly 'online' to a researcher abroad. Videos made on insect specimens are already being exchanged across the Net.

It is evident that it will take time to establish such museums. Till then we must do with "virtual museum". Here, in this virtual museum we can share all our images of a given group. Taxonomists can take advantage of this new tool again, either by creating their own website, with images of all their specimens, or join hands with some group who can do that. At present Western Ghats Biodiversity Portal is making such tool available freely for all (layman, naturalists and, of course, scientists). All we have to do is go on adding images with relevant data. The images of course must be excellent digital images of properly mounted or pinned specimens showing important taxonomic characters of that order. Of course, for some very speciose and uncommon insect genera, exchange of specimens is a must; images alone are not sufficient. A taxonomist with decades of experience can definitely give you identification, at least up to generic level, on the basis of good images sent by e-mail. Later work you can do with literature. *Free, but limited exchange of specimens for research purpose is a universal requirement, however, and this need should be recognized by all concerned.* Identification of a species is not done just for answering the local requirement; a species is a global phenomenon and must be treated as such. It must eventually be put in global context and, for that purpose, comparison with other related species is absolutely necessary. This is only possible with exchanges of specimens. Researchers doing phylogeny cannot complete work unless specimens from all over are available for comparison.

In the days when phylogenetic relationships are being studied, we also need ultra-structural details. A scanning electron microscope (SEM) is now an indispensable tool for insect taxonomy; SEM details of setae on antennae, details of the structure of scent glands and the surrounding area in heteropteran insects, details of the egg chorion, etc. are but a few things that are being actively used by taxonomists abroad; however, very little work of this kind is done in our country. With compact 'table-top' SEMs now available, it should not be very difficult for museums and institutions to install one for taxonomic work. It will be a great boost.

A rich library is another essential thing, and we need that badly in India. There are almost no libraries that have older volumes of many important journals dealing with taxonomy. Taxonomy requires the oldest references as taxonomic descriptions are like 'legal documents', bound by international rules framed by the International Commission for Zoological Nomenclature, or ICZN. At least one central library with as many journals as possible is required in our country. The problem has been solved partly by the Biodiversity Heritage Library, which is making many older journals, with which there is no copyright problem, available through the Internet. Some literature on particular groups is also available at cost with private dealers, and that is also useful. Collaboration among taxonomists, *i.e*. sharing copies among fellow workers, is equally necessary. It is the experience of most taxonomists that a lot of time and energy is spent in collecting essential literature.

Another useful modern tool that can be very useful is obtaining DNA barcodes for all insects for the gene cytochrome c oxidase I (COI) sequence, using universal primers, as suggested by the Barcoding of Life Project. This is also called DNA barcoding. This approach has been severely criticized by some as a 'fashion', and several heated discussions have taken place in the past few years. A good question-and-answer paper for all the criticism is available on the Internet (Hebert and Gregory, 2005), and there is no need to reiterate everything here. A critical appraisal has been provided and possible shortcomings, etc. have been discussed in detail by Rudolf Meier (2008). However, it has been accepted that the technique most certainly will help identification of local faunas. Meier (2008) is also of the opinion that 'integrative taxonomy', which combines morphological as well as DNA-based techniques, will prove to be very useful. It is most certain that DNA barcoding is not going to replace morphological taxonomy, which has been practiced for over 250 years. Even DNA barcoding is at present being done on morphologically identified species, but in the future it will be used to identify a species based on a DNA sequence obtained from just a few cells from any muscle or even from an egg, larva or pupa. A DNA sequence is to be looked at as another set of data, and all data are useful in taxonomy. In fact, with the powerful tools of various computer programs, it is easy to compare sequences rapidly and look beyond species identification. A DNA sequence from a related species of the same genus or a related genus, or even a related family, can be easily recognized as the database of sequences becomes rich. Another very important aspect of using DNA sequences is that one can relate eggs / larvae / pupae and adults, something that is difficult unless one rears an insect under lab conditions. It is true that sequences alone do not define a species. It must be morphologically described. But what is the harm if, in addition to traditional morphology, we also sequence a particular gene and add that data? For older taxonomists it may be difficult to learn these newer techniques, but rather than shirking away from such useful tools they should collaborate with molecular biologists and do it. One cannot deny that the ultimate aim of all taxonomy is to delimit species, and finding phylogenetic relationships and DNA sequences will be very useful in this regard. Already a vast number of molecular phylogenies have been published, and many more are on the way. These molecular phylogeny hypotheses are testing the previous hypotheses, which were entirely based on morphology, as has been recently done for Pentatomomorpha bugs (Grazia *et al*., 2008). In some cases there is a good congruence between the two hypotheses, and in some cases there are discrepancies. No doubt much research is needed to settle these questions, and a good beginning has already been made. Indian taxonomists must take an active part in this progress as we have a diverse fauna, and data on Indian species will help settle many questions about the origin of our species: for example, how many are Gondwanan relicts, or how many are Indo-Malayan elements, or how many species are just invasive that have recently been introduced, etc. In fact, a whole lot of biogeographical hypotheses are being formed and tested using these modern tools, and a few Indian scientists are also part of this, but a larger involvement is necessary. Otherwise we will lag behind. In this modern biology scenario, we cannot go ahead at all ignoring molecular data. It must be mentioned that the costs of DNA isolation, gene amplification and sequencing have gone down considerably and most techniques are automated, leaving a very narrow margin of error. A good DNA sequencing lab is thus a special asset, and taxonomists must seek to collaborate with such labs as an entirely new set-up for sequencing means a lot of cost in infrastructure—not that such expenses are beyond the means of all our universities or national institutions.

Collaboration is yet another important issue. It is true that single workers have contributed significantly to taxonomy, but even these people have depended on other workers for some or the other kind of help. But now if we are to speed up the work, taxonomists must form large interactive groups that are dedicated to a particular group / family of insects. There are such groups abroad, the Coleopterists Society (USA), the Orthopterists' Society (USA) and the International Heteropterists' Society (USA), for example, which are doing much work with mutual help. It is not that we do not have societies of scientists; the problem is that most of these are 'not visible' in terms of the work achieved. We need to form large working groups and keep them free of politics. Mutual work alone must be the sole aim of such societies, not elections for presidents, secretaries, treasurers, etc. In our country there are a few such societies but a journal like 'Entomon' is a product of one such grouping. Taxonomists in India must freely and regularly communicate with each other and exchange specimens and literature, and this is possible at negligible cost due to the Internet. It is easy to send a series of photographs of a doubtful specimen and get opinions from other taxonomists; an actual specimen may be needed only for dissections or other critical measurements. In a science that is rapidly advancing, we cannot remain isolated. But this is not happening on a large scale. For example, a large group of workers dedicated just to the Pentatomidae of the Western Ghats will achieve much more than isolated workers, who can never travel to all parts unless they spend years collecting. Collaboration with foreign scientists will be of great help as their museums are very rich, their methods of collection and specimen preparation have been perfected, and overall they have other rich resources. Many European taxonomists are interested in Oriental insects, and many are interested in establishing a global phylogeny, and for them Oriental material is very important. Healthy collaborations between Indian and European institutions will speed up the process of biodiversity research. The government should encourage and finance such projects, as it does with biotechnology projects.

Collaboration with naturalists/field biologists/amateur taxonomists will also be very useful. In fact it is necessary. Local people with knowledge of local biota can also be recruited as 'parataxonomists'. It will be necessary to train these people in the basics of collection and preservation of specimens. These people often live close to collection areas and can visit these areas more frequently than taxonomists can and may even visit areas inaccessible to taxonomists for various reasons. Taxonomists also do field work, but their time and energy can be saved for better work later. A regular supply of specimens will then be available to taxonomists without their resorting to field work often. An extremely good example of the involvement of parataxonomists can be seen in the Costa Rica Project [see Janzen and Hallwachs (2011)]. According to the scientists involved in the above project, a parataxonomist is "…a person derived from the rural work force who has been on-the-job trained, facilitated, and stimulated to be able to carry out the same performance of biodiversity inventory in the field as could / would a graduate student or post-doc in taxonomy / ecology ...". We have many such people available in our rural / tribal areas and these people can be trained for this purpose. We need to think seriously about this. These people can be useful in conservation.

Rules and regulations about animal collection / exchange already have many problems. This aspect needs serious attention, and much has already been written about this in scientific journals [see Bawa (2006), Madhusudan *et al*. (2006), Prathapan *et al* (2006, 2008 a,b)]. A large number of taxonomists must make a representation and do something to prevent suppression of taxonomical work in our country. Of course, wanton collection and destruction of insects (and plants as well) by undergraduate students should be controlled/regulated. Commercial exploitation can lead to extinction of any species (this has happened even for plants and large animals due to human greed); scientific collection for research has never resulted in the total loss of a species [see Ghorpade (2010) for more on this]. Species are global or universal phenomena. As aptly pointed out by Wheeler (2008c), again, 'No taxonomists can work in complete isolation. No taxon can be known without global sharing of data and specimens'. A species after all is also a 'hypothesis', and it must be 'tested' as more and more data come in. Delimitation of a species is a continuous process!

Perhaps a very good, recent example of large groups doing taxonomical work together is the US National Science Foundation's "Planetary Biodiversity Inventories program" (Page, 2008). In these projects taxonomists from all over the world come together for sorting out taxonomy of a large clade of organisms - one such interesting project is on Catfishes of The World. There are a few thousand images of various catfishes of the world on their website; also available is literature and expertise from a large assemblage of taxonomists working towards a common goal. Why we also should not initiate such project for insects, may be for the Oriental Region at least? Several bugs and beetles are problematic for our economically important trees / crops and a collaborative project will help solving problems. This will also help us plot the distributional data on our species, which at present is very scarce indeed. Without factual data on distribution of species, we cannot talk about endemism, etc.; nor can we plan to conserve an important species, if need arises. We just do not fully know what we have and where (distribution data) !

Publication of papers is yet another field that must undergo a significant change as far as the Indian scenario is concerned. Journals publishing new species descriptions must be fully aware of the ICZN rules. Many new 'online journals' have suddenly mushroomed in the wake of the rapid development of the Internet and the 'craze to publish' among new researchers, either for the sake of increasing the numbers of their publications or for scoring some points to get ahead in the pay-scale! This is going to bring down the quality of publications and eventually the quality of the science being published. Severe regulations will be required in the near future to counter this threat. Otherwise, like the paid-news that we see every day in newspapers, research papers will also be 'paid-publications', with no monitoring of quality. Unnecessary importance is placed on the number (quantity) of publications than on the quality of publications, a fact certainly detrimental to science.

Preparation of websites with information that is freely available to everyone is another way of getting the results of taxonomy to the public as well as experts. The cost involved in hosting such websites is not formidable at all. A very useful website for the Cassidinae of the world (from Leach Borowiec and Jolanta Swietojanska of Wroclaw Univerity, Poland) is functional for some years now; similarly, very useful websites for the Coreoidea (Livermore et al, from the Natural History Museum (NHM), London) and the Pentatomoidea (David Rider, North Dakota State Univerity, USA) of the world are freely available. The Cassidinae website contains very good photos, valid names and synonyms, information about type material, distribution data and information about host plants, as well as references. In the Coreoidea website, it is also possible to get linked to an actual reference through the Biodiversity Heritage Library and to get a PDF. A website on the family Cerambycidae has hundreds of photos and a list of useful references, some of which are available in the PDF format. Antbase is a similar website for ants. These are just a few examples (all listed at the end), and we need to do something for our species urgently. A good website for Indian species of ladybird beetle, or the family Coccinellidae, is available due to the efforts of J. Poorani, from Bangalore, and has very good pictures, keys, etc. Similarly, a website for the Odonata of the Western Ghats, as well as an e-book on the Odonata, has been developed by Subramanian of the ZSI. In spite of a well-developed informatics community, we have not been able to harness their help fully, and much needs to be done in the field of what can be called 'web taxonomy'. More and more websites should come up rapidly in the future, and these will attract the attention of students and will make them interested in taxonomical work. Expert taxonomists who have spent years with a particular group can also participate by creating e-documents/ e-lectures and videos to teach the taxonomy of that group to a wider audience via the Internet. This is easily achieved with the fast Internet that is with us now. Even scientific reports of various biodiversity projects funded by the UGC/DST/DBT can be floated on the Web, as done for the Shivalik Cicindellidae (Uniyal and Sivakumar, 2007), with colour images that can help non-taxonomists. If students can grasp the wealth of biodiversity we have through the Web, I am sure more students may opt to do taxonomy. The current generation of students and people between 20 and 35 years of age are computer savvy, and it will be best to approach them via the Internet. Even Facebook chats involve biodiversity, and there was news that using a Facebook contact, a student identified some very rare fishes from remote streams.

People who have faith in modern technology firmly believe that automated image analysis and identification will give rise to small hand-held devices like an i-Pod that can store thousands of images. This device will be Internet-connected and will be able to compare newly taken images with available images and provide the closest name. For local floras, this has already been made possible through excellent images of flowers. For birds and butterflies too, this is on the way. Once again this will be an immense help in settling taxonomic questions and biodiversity studies, and so we must invest money and energy in such endeavours.

It has often been claimed that taxonomists write for their own pleasure and for their own sake. The main reason for this criticism is that taxonomical papers contain few good illustrations and include difficult terminology. Taxonomical descriptions are difficult for the layman (end-users of taxonomy such as students, farmers, naturalists and conservation biologists), and although it may not be always possible to simplify each term, it certainly is possible to illustrate well. Yet another lacuna in the older taxonomical literature is that many species descriptions are just three to five lines long, that too in Latin, and are without a single illustration. Although the situation has changed with new rules of nomenclature, the problem remains the same with the older literature. What can be done for this? I think a major initiative by groups of taxonomists can be the re-description of all species and preparation of a copious number of illustrations. In the past, publication of many figures and photos was costly, and the authors were charged; with new online publications, any number of relevant figures and photos are accepted even in full colour. Why not take advantage of this? If senior taxonomists themselves find the re-description business less attractive, such work can be assigned to post-graduate students as project work. But re-descriptions with colour photos showing important characters may be one very important means of attracting students and naturalists. This will help rapid identification and thus help conservation biologists as well. One of the reasons why butterflies and birds are popular is that lots of illustrated field guides are available for these groups. Is it impossible to prepare such illustrated field guides with simple keys for different groups of insects? If not, why is a concerted effort not directed towards achieving this goal? It is necessary to pause and think positively in this regard. Even monographic works on tribes, genera or even families can be published as e-monographs as it is difficult to find publishers for such works. It is a lot easier to constantly revise such monographs as new information comes in, something that is not possible with printed monographs. In addition, most of the former 'keys' for identification are clumsy and are decipherable to only a few people. If these keys are modified to accommodate drawings/photos, then such 'illustrated keys' will have a significant impact.

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INDIAN INSECT AND SPIDER DIVERSITY: RICHNESS ESTIMATES BASED ON TRUE FLIES OF THE WESTERN GHATS AND A PROTECTION STATUS ASSESSMENT

Kumar Ghorpadé

Post-Graduate Teacher and Research Associate in Systematic Entomology, University of Agricultural Sciences, Krishi Nagar, Dharwad 580 005, Karnataka, India.

email: kumarsinh.g@gmail.com

ABSTRACT

This article summarizes known information on the true, two-winged, flies known from the Western Ghats biogeographical sub-area. This group is used as an indicator of the total insect diversity assumed to exist on these mountains, in Dravidia (central & peninsular India and Sri Lanka) and the Indian subregion, by perspective. The Western Ghats, a north–south mountain range running south of the River Tapti (Tapi), in Gujarat, to Cape Comorin (Kanyakumari), Kerala–Tamil Nadu, has some 1,262 known, described and recorded fly species of 540 genera in 64 families. Perhaps another 825–950 or more species still fly in and inhabit the Western Ghats but are not yet collected, named and described, and other known species are currently not recorded from this hill range. Statistical inference suggests that the Western Ghats may possess some 52% (or 50–70 %) of all Diptera species found in the "Peninsular India–Ceylon" biogeographical area but only 15% (or 15–25 %) of the fauna in the Indian subcontinent (subregion). The Western Ghats have 7–10% of the species found in the Oriental region and 2–4% of the Diptera found on earth. By extrapolation, it is estimated that around 20,000 insect species (2,000 Diptera) inhabit the Western Ghats, 40,000 in Dravidia (4,000 Diptera) and 1,50,000+ (15,000 Diptera) in the Indian subregion. Only by protecting (and restoring) all remaining pristine and minimally disturbed habitats in India (ca. 3% remaining ?) by legal and military action can its biota be hopefully saved for posterity and our environmental good health, this dependent mainly on urgent human (and livestock) population control.

"Simplicity is attained after learning,
Lack of this profound knowledge creates confusion."

INTRODUCTION

The Western Ghats "hotspot" is a north–south oriented mountain range with one end located just south of the River Tapti (Tapi) in Gujarat state, where the Surat Dangs occur, extending some 1,600 km from there as the highest altitudinal aspect in southern India through the states and union territories of Daman, Dadra–Nagar Haveli, Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala to what are called the Ashambu and Papanasam hills, straddling the Tamil Nadu–Kerala political border near Cape Comorin (Kanyakumari). Some portions of these high hills are also locally termed the Sahyadris in Maharashtra and the Malnaad in Karnataka. The precipitation on these hills ranges from some 1,000 to 7,000 mm per annum, and the highest peaks soar to heights of over 2,500 m. Some peaks, proceeding from the north to the south, are Kalsubai (1,646 m) and Mahabaleshwar (1,438 m) in Maharashtra, Bababudangiri (1,892 m) and Kudremukh (2,027 m) in Karnataka, Dodabetta (2,633 m) in Tamil Nadu and the highest, Anaimudi (2,695 m), in Kerala. Of the 182,500 km^2 of original forest area, less than 7% (12,450 km^2) now remains on the Western Ghats.

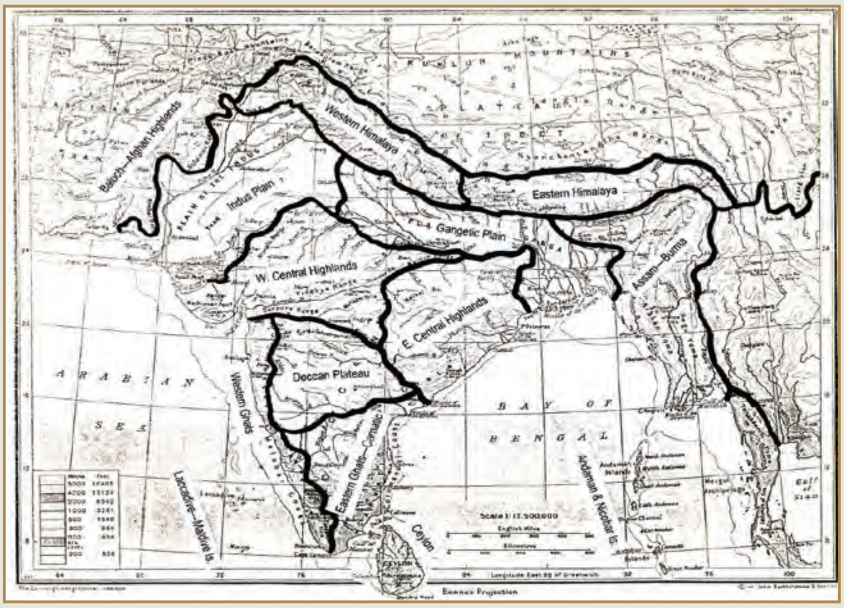
There are about 4,780 species of plants in the Western Ghats, of which 2,180 (46%) are currently found to be endemic. Of the 1,073 vertebrate species on these mountains, about one third (ca. 30 %) are endemic. Similarly, 38 (27%) of the 140 species of mammal, 40 (8%) of 528 bird species (this endemism proportion needs to be re-evaluated), 161 (62 %) of 259 reptile species, 204 (76%) of 269 land snail species, 116 (80%) of 146 amphibian species, and 111 (46%) of 241 freshwater fish species are also endemics in the Western Ghats, which is ranked seventh among the 25 global hotspots in relation to endemic plant and vertebrate endemism, their area ratios, and percentages of remnant vegetation to original extent. The insect diversity is here computed to be not less than 20,000 species on these ghats, 40,000 in Dravidia, and 1,50,000 in the Indian subregion. For more information on these ghats, the following may also be consulted: Bhimachar (1945); Champion & Seth (1968); Croizat (1968); Mani (1974); Meher-Homji (1983); Nayar & Sastry (1987); Pascal (1988); Gadgil (1996a); and Chandran (1997).

The geographical scope of this paper–the Western Ghats–is a major re-focus on natural areas, rather than a continuation with the otherwise political (country, state, district) units selected for scientific documentation (of plants or animals) that I consider are highly artificial and irrelevant (except politically) in biogeographical, evolutionary or purely scientific terms. It is therefore recommended here that we need to identify and study the fauna and flora of these individual biogeographical areas, rather than those of political units.

THE FLORA AND BIOGEOGRAPHY OF THE WESTERN GHATS

Subramanyam & Nayar (1974) provided a very important database on the flora of the Western Ghats. They wrote (pp. 178–182) that "...the vegetation is influenced more by the abundance and distribution of the seasonal rainfall than the atmospheric temperature" and that ".... the flora of the leeward side of the Western Ghats merges with the floristic elements of Deccan [also of the Eastern Droogs q.v., vide infra–K.G.]. The exact boundaries of the botanical provinces of Malabar [the Western Ghats sub-area of mine, see Map, Figure 2] and Deccan [Deccan Plateau and Eastern Ghats (Droogs)–Carnatic sub-areas of mine, q.v., Figure 1] are not sharp, as large number of spurs of the Western Ghats enter into Deccan and merge with the mountains of the Eastern Ghats. So also in the north the Vindhya and Satpura ranges, Mahadeo Hills carry some of the deciduous floristic elements to Central India." They also stated that the Western Ghats flora is distinctive in the primary presence of the plant families Bambusae [now Poaceae–K.G], Dipterocarpaceae, Guttiferae [Clusiaceae], Myristicaceae and Palmae [Arecaceae]. The "ten dominant natural Orders are Gramineae [Poaceae], Leguminosae [Fabaceae], Acanthaceae, Orchidaceae, Compositae [Asteraceae], Euphorbiaceae, Rubiaceae, Asclepiadaceae, Geraniaceae and Labiatae [Lamiaceae]." The Western Ghats have some 1,500 endemic species, they wrote, out of 2,045 endemic dicotyledons in peninsular India, in comparison with 3,165 endemic dicots in the Himalayas (Chatterjee, 1939: 30). But Subramanyam and Nayar (1974) divided the Western Ghats into four, not three, 'Phytogeographical regions', i.e. –(i) The ghats from the River Tapti to Goa, (ii) the ghats from the River Kalinadi to Coorg, (iii) the Nilgiris and (iv) the Anaimalai, Palni and Cardamom hills.

Figure 1.



Biogeographic divisions of the Indian subregion

There are three reasonably distinct geological and biological divisions of the Western Ghats (in India) as theorised based on studies of fish distribution by Bhimachar (1945) and subsequent research by other workers. The geologically separated island of Ceylon (Sri Lanka, politically) was once part of the older Gondwanaland-originated and split 'Greater Indian Plate', and the high country there, as the hilly area is popularly termed in Sri Lanka, is also biogeographically part of this significant, newly uplifted, north–south-oriented mountain range on this ancient land that has never lain under water (vide Forster, 1924). Of the three divisions (there is a fourth in Ceylon, see Fig. 2), the first is what I have named the Dangs–Konkan biogeographical sub-sub-area (the Northern Division of Bhimachar, 1945), from the Dangs in Gujarat south to all of Goa and the Kalinadi River. The second is the Canara–Malabar (Central Division), from the Kalinadi River to the Nilgiris north of the Palghat Gap barrier. The third is the Travancore–Cochin sub-sub-area (Southern Division) from south of the Palghat Gap (Nelliampathy–Anaimalai hills) to the extreme southern tip of India near Kanyakumari (Ashambu–Papanasam hills).

These are also exactly the biogeographical sub-sub-areas of the Western Ghats that were identified (see Ghorpadé, 2001). Figure 1 gives the main biogeographical divisions of the Indian subcontinent that form the Indian subregion of the Oriental Region. Simply put, the Greater Indian Plate, which was once part of the southern hemisphere supercontinent Gondwanaland, now exists only as the Central Highlands and peninsular India–Ceylon areas south of the Indo-Gangetic Plains. These latter plains are recently formed land, overlaying the Tethys Sea, which previously existed there. More of this Indian Plate now lies crumbled below the Arabian Sea and the Bay of Bengal, the latter being an important "node" (vide Croizat, 1968) which divides the life that occurs from Afghanistan to Sri Lanka (Indian subregion) from what does south of the Yangtze-Kiang River in China to the Malay Archipelago (Sino–Malayan subregion), including Malaysia and Indonesia. The Himalaya (see note 1), along with the Baloch–Afghan mountains and the Naga–Arakan hills, form the northern mountain arcs, which are, mostly, the transition of Palaearctic (high elevations) and truly Oriental (lower altitudes) biota. The Irrawaddy River Valley in Burma (Myanmar) separates the Indian subregion to its west from the eastward Sino–Malayan subregion. The Sino-Malayan subregion includes areas in eastern Burma such as the Shan States and the Tenasserim Isthmus. The Andaman and Nicobar Islands are perhaps peaks of once high mountains that existed on the Greater Indian Plate, of which a part has now sunk into the bay. It should be noted that in the Peninsular India–Ceylon biogeographical area, which is the oldest surviving geological landmass in the subregion, both the Western Ghats and the Deccan Plateau sub-areas are recent formations, the former formed by faulting (see B.P. Radhakrishna, 1992, J. Geol. Soc. India, 40: 1–12) and the latter through gradual, fissured volcanic action, some 50 million or more years ago. Hence, the Eastern Ghats (Droogs)–Carnatic sub-area, or what still remains of it without human destruction or disturbance, is the oldest and most 'Gondwanan' portion of this subcontinent and contains the most ancient flora and fauna surviving here. It is this land area of the peninsula that has most probably sourced the new biota evolved on the Western Ghats, some of which have adapted to the semi-arid Deccan Plateau as well. The Tapti and Godavari rivers (actually Tapti–Purna–Bemla–Wardha–Pranhita–Godavari) form the northern boundary of the peninsular India–Ceylon biogeographical area and are a major distributional barrier, keeping distinct non-mobile fauna such as species of macaque and junglefowl and flora on each side, isolated from each other.

Misled by the unique and special lifestyle adaptation of some migratory birds whereby they escape life-threatening climatic changes in the winter months, it is being generally assumed that most other birds also 'disperse' willingly and easily, whenever they need good, sustainable habitats (for food or nesting). Croizat (1968) however emphasized that 'land and life' move and evolve together and warned that some present living plants and animals may be much older than recent geologic changes. Current scientific thought leans more towards vicariance biogeography, and the 'dispersal' paradigm (*e.g*., Meher-Homji, 1983, *etc*.) may be an inappropriate and untrue model applicable only to new ecosystems such as oceanic islands rising above sea level, opening up virgin 'empty' habitats (cf. MacArthur & Wilson, 1967; Quammen, 1996) and then gradually being colonised, mostly by accidental or chance 'invaders'. Srinivasan & Prashanth's (2006) 'dispersal routes' to the Western Ghats appear to me inconclusive (see more appropriate and biogeographically proven, or hypothesized, theories in Karanth (2003) and Ghorpadé (2007)). Hora's 'Satpura Hypothesis' is dead and buried now, and my thought process tends to agree with Croizat's (1968, not 1949, vide Srinivasan & Prashanth (2006)) analysis about the 'fundamentals' of the Indian subregion's biogeographical history.

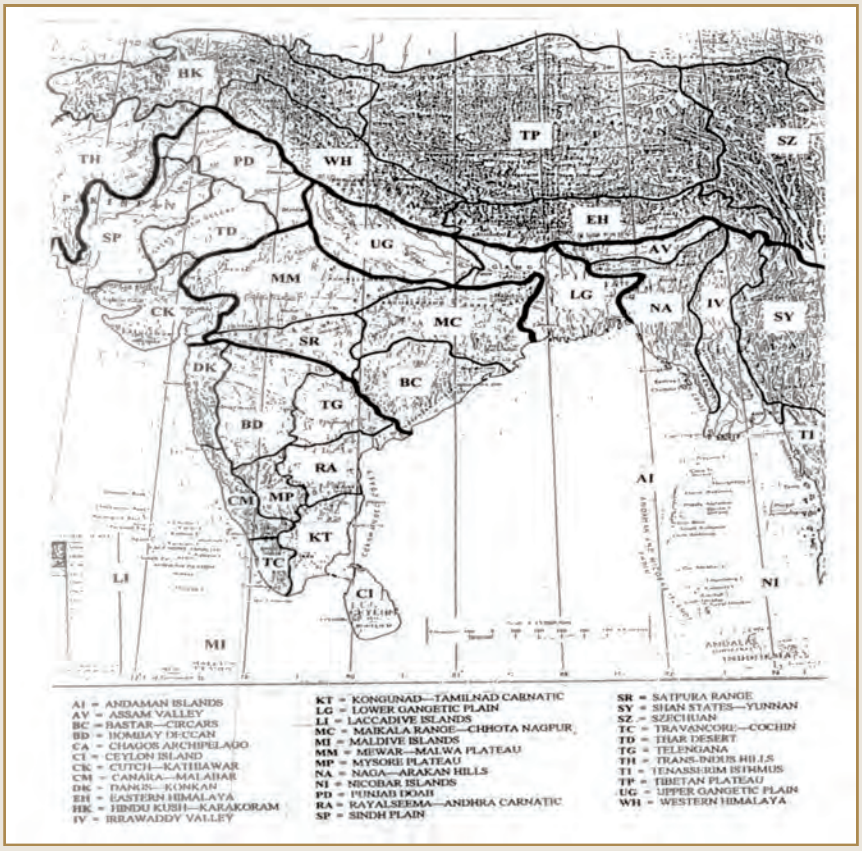
Gadgil and Meher-Homji (1982, 1986, q.v.) identified nine forest types that make up the floristic diversity and ecosystems in the Western Ghats. Nayar (1994) wrote on the hotspots of plant diversity in India and gave specific locations in the southern peninsula–Agastyamalai, Kalakkad; Guderikal-Sabarigiri; Periyar, Varushanad, High Wavy Mountains; Anaimalais, Parambikulam; Silent Valley, Wynaad, Nilgiris; Coorg, Brahmagiri; Agumbe; Radhanagari; Koyna, Mahabaleshwar.

As "centres of endemism", he listed the Mahabaleshwar–Khandala ranges, Agumbe–Phonda ranges, Ratnagiri–Colaba ranges, Silent Valley, Nilgiris and Wynaad, Anaimalais, Palnis–Yercaud, and Agastyamalai–Kalakkad. I consider Coorg and the Bababudan Hills also as other Western Ghats hotspots, but the latter were omitted by Nayar. These hotspots for plant diversity need to be compared with and corroborated by similar studies on the richness of the faunal taxa of these high mountains, including their true two-winged flies, the Diptera.

Vats *et al.* (1999) warned that several grass species of our subcontinent may be on the verge of extinction. The sholah–grassland ecosystem on the high ranges of the Western Ghats, especially the central and southern divisions, needs to be studied and sampled for its Diptera (and other insects) that have adapted to the grass species that evolved here. Similarly, Henry *et al.* (1979) listed 224 species of flowering plants from "south India", of which a huge majority, 208 species, threatened in their native habitat, are found on these ghats.

Thapar (1977) gave a map depicting the socio-cultural sub-regions in India inhabited by its human population, which I found interesting to compare with the wildlife regions . The Western Ghats extend over eight of these: Khandesh (southernmost Gujarat and northern Maharashtra), Konkan (western Maharashtra and Goa), Desh (eastern Maharashtra), Bombay, Karnatak (southern Maharashtra and north-western Karnataka), Old Mysore and Malnaad (southern Karnataka), Malabar (northern Kerala), Kongunad (western Tamil Nadu), and the Kerala Coastal Plain (southern Kerala).

Figure 2.



Biogeographical areas, sub-areas and sub-sub-areas of the Indian sub-continent.

CURRENT STATE OF KNOWLEDGE

Beyond the information provided for the Western Ghats, for perspective, the known numbers of genera and species of each family of Diptera occurring on the continental island of Ceylon, in the biogeographical area of peninsular India–Ceylon, and in the Indian subcontinent are also provided (see Table I). The sequence used for the families listed in the table is that adopted by the Biosystematic Database of Diptera of the World, created and updated at the United States National Museum of Natural History, Washington, DC, U.S.A. But the splitting of families such as Tipulidae and Mycetophilidae, and the transference of others such as Conopidae from Brachycera to Cyclorrhapha, *etc.*, is not followed here. More thorough sampling of the tropical fauna and phylogeny based on more extensive, complete databases offering a better understanding (see also Ghorpadé (1998): 4) are awaited. The data presented below are from my research files (see also Ghorpadé, 1979, 1997b, 1998), kept and updated since 1973, and are sourced from original catalogues, checklists, monographs and revisions. Moreover, the names in most of these were annually compiled by the abstracting periodical Zoological Record (Insecta), which was also searched.

Table 1 .

Flies known from some portions of the Indian subcontinent.

Taxon	W. Ghats	Ceylon	Pen. India+Ceylon	Indian subregion
Order Diptera	540–1,262	611–1,321	823–2,279	1,600–7,887
Nematocera	144–416	156–400	223–795	479–3,196
Tipulomorpha				
Tipulidae	60–214	41–111	68–319	150–1,565
Psychodomorpha				
Psychodidae	11–19	7–21	13–40	23–99
Scatopsidae	1–1	2–2	2–3	4–5
Culicomorpha				
Dixidae*	0–0	1–1	1–1	1–12
Chaoboridae	1–1	2–2	2–2	2–4
Culicidae	23–81	35–118	36–169	45–341
Ceratopogonidae	12–14	16–36	21–48	34–214
Chironomidae	2–10	5–29	7–40	32–236
Simuliidae	3–13	3–6	3–15	6–63
Blephariceromorpha				
Blephariceridae	2–2	1–2	3–4	6–23
Bibionomorpha				
Anisopodidae*	0–0	2–4	2–4	2–11
Bibionidae	1–3	1–3	1–6	4–52
Mycetophilidae	2–2	21–38	21–39	39–114
Sciaridae	2–2	4–8	4–8	6–61
Cecidomyiidae	24–54	15–19	39–97	125–396
Brachycera	70–224	98–233	118–396	247–1,464
Stratiomyomorpha				
Xylomyidae	1–1	1–1	1–3	3–27
Stratiomyidae	4–6	18–27	19–33	43–122
Tabanomorpha				
Rachiceridae	1–2	1–4	1–6	2–10
Tabanidae	7–41	10–35	12–73	18–191
Rhagionidae	2–5	2–6	3–13	4–51
Nemestrinidae*	0–0	3–4	3–4	4–11
Acroceridae	1–1	2–3	2–4	10–18
Vermileonomorpha				
Vermileonidae	1–1	0–0	1–1	1–1
Asiloidea				
Therevidae	1–1	3–8	3–9	5–20
Scenopinidae	1–1	1–2	2–4	2–4
Mydidae*	0–0	0–0	1–1	1–5
Asilidae	22–91	20–37	24–62	55–482
Bombyliidae	11–25	13–26	16–58	25–123

Empidoidea				
Empididae	5–5	8–25	11–29	42–185
Dolichopodidae	13–44	16–55	19–96	32–214
Cyclorrhapha	320–622	357–688	482–1,088	847–3,227
Aschiza				
Phoridae	12–18	8–11	18–29	38–134
Platypezidae	1–1	2–2	2–2	3–6
Pipunculidae	3–15	3–7	4–19	10–127
Syrphidae	30–59	35–73	38–99	80–355
Conopidae	5–6	5–10	6–16	12–57
Calyptratae				
Hippoboscidae	3–3	7–10	9–12	16–43
Nycteribiidae	7–13	8–13	8–18	8–40
Streblidae	3–4	2–6	4–9	4–12
Anthomyiidae	2–2	4–5	7–11	18–56
Fanniidae	1–2	2–2	2–3	2–7
Muscidae	32–121	35–131	36–179	57–363
Eginiidae	1–1	0–0	1–1	2–2
Calliphoridae	17–25	15–35	17–48	30–128
Sarcophagidae	24–44	23–39	34–71	60–248
Rhinophoridae*	0–0	1–1	1–1	3–3
Tachinidae	50–71	47–67	81–125	160–333
Gasterophilidae	2–4	1–3	2–5	3–6
Oestridae	1–1	1–1	3–3	7–7
Acalyptratae				
Nerioidea				
Neriidae*	0–0	4–4	4–4	4–6
Micropezidae	1–1	3–5	3–6	4–14
Megamerinidae*	0–0	1–1	1–1	1–2
Diopsoidea				
Psilidae	1–1	1–1	1–1	4–14
Diopsidae	3–3	1–4	3–7	6–15
Tephritoidea				
Pyrgotidae	1–1	2–3	3–4	6–17
Tephritidae	27–39	39–62	49–92	97–306
Platystomatidae	3–9	7–19	10–29	21–80
Otitidae	1–1	1–2	1–2	2–6
Lonchaeidae	4–7	3–10	4–14	4–15
Lauxanioidea				
Lauxaniidae	8–12	14–25	16–32	20–55
Celyphidae	3–6	2–4	2–8	3–15
Chamaemyiidae	2–2	2–2	3–3	4–8
Sciomyzoidea				
Sciomyzidae	1–5	1–3	1–5	6–13
Sepsidae	5–13	6–10	6–16	8–21

Opomyzoidea				
Aulacigastridae	1–1	1–1	2–2	2–3
Asteiidae	1–1	1–1	2–2	3–4
Agromyzidae	12–38	7–15	12–44	19–184
Fergusoninidae*	0–0	0–0	1–1	1–1
Carnoidea				
Milichiidae	2–3	1–3	2–5	3–10
Chloropidae	30–42	26–38	37–67	70–269
Canacidae*	0–0	2–2	2–2	2–3
Cryptochetidae*	0–0	1–1	1–1	2–2
Sphaeroceroidea				
Sphaeroceridae	1–1	6–9	7–10	12–42
Ephydroidea				
Ephydridae	9–15	11–16	15–26	28–51
Curtonotidae*	0–0	2–2	2–2	2–4
Drosophilidae	10–31	13–29	18–51	27–140

NOTE

There are 11 families asterisked above, which are not recorded from the Western Ghats, though they are known from Ceylon, plus the family Mydidae, known only from Tranquebar, on the eastern Coromandel Coast, and the family Fergusoninidae, recorded from Hyderabad (in the Andhra Deccan) and Bangalore (unpublished data). The Western Ghats totals have been updated for some families, but the figures for most others are taken from Delfinado & Hardy (1973, 1975, 1977). Information on other families recorded from the Indian subcontinent or from other subregions of the Oriental Region but so far not found in peninsular India–Ceylon is given elsewhere (vide supra, pp. 12–13).

BRIEF ACCOUNT OF DIPTERA FAMILIES FOUND IN THE WESTERN GHATS

A preliminary appraisal of Diptera taxonomy in the Indian subcontinent was given by me (see paragraphs quoted here below and summaries in Ghorpadé (1998) and in Brown (2001)), which provides a synoptic database on the true flies of India and adjacent countries. See also Oosterbroek (1998, 2006) for a good synopsis of Malayan and European families. Oldroyd (1964) is a 'pleasure read' book on the natural history of true flies. Information in Ghorpadé (1998, q.v.) is not repeated in this paper, but ideas from it offer information on the economic importance of the Diptera and present a brief account of the history of research on the flies in the Indian subcontinent and elsewhere.

"The major interest of man with flies has been in preventing or controlling diseases, of humans and their livestock or pets, transmitted by species of Diptera. Besides the Culicidae, members of the families of Calliphoridae, Ceratopogonidae, Gasterophilidae, Hippoboscidae, Muscidae, Nycteribiidae, Oestridae, Psychodidae (including Phlebotomidae), Sarcophagidae, Simuliidae, Streblidae and Tabanidae are involved. As crop pests, flies aren't as important as beetles, bugs or moths for example, but some serious injury to cultivated plants is caused by species of Agromyzidae, Anthomyiidae, Cecidomyiidae, Chloropidae, Muscidae and Tephritidae. The beneficial aspects of True Flies are connected mainly to their propensities either as predators or parasitoids of destructive insects or other animals, or as pollinators of economic or ornamental plants. The vast majority of the Diptera biodiversity is hardly thought useful to be sampled and studied, let alone be compartmentalized by us as 'harmful' or 'beneficial.' The ecology ('scientific' natural history) of Diptera is shamefully sidelined, even by Dipterists, they either choosing to pursue taxonomic research (with phylogenetic and evolutionary 'mirages' and 'flights of fancy' enlivening the mundane nitty-gritty of description of dead specimens), or opting for better funded microentomology, biotechnology, molecular biology, DNA-based studies, or even 'conservation,' now!"

"The history of Indian Dipterology has not been satisfactorily updated for the past 75 years, since Ronald Senior-White (1923) published his notes on the 'Recent progress in our knowledge of Indian Diptera'. Before him, Enrico Brunetti (the 'Father' of Indian Dipterology, without any doubt–see his Obituaries in Prashad, 1927 and Senior-White, 1927, and references to more of them in Thompson & Ghorpadé, 1992: 10) had written reviews on 'Our knowledge of Oriental Diptera' in 1910 and 1919. Ghorpadé (1998) gave the most recent, brief appraisal of our Diptera taxonomy, updating research done on flies in this subcontinent.

Howlett (1909) had drawn up the first Indian overview of the Diptera in this subcontinent, at a time when an estimated 1,000 species of flies were known from here, this figure doubling W.T. Blanford's (1881, Journal of the Asiatic Society of Bengal, 50: 263) earliest 'numerical enumeration' (see Indian Insect Life, pp. 14–15). T. Bainbrigge Fletcher (1920: 993–994), the Imperial Entomologist then, wrote that "The Diptera were listed by myself in 1910 and the card catalogue made then is presumably still in the Imperial Pathological Entomologist's Section". Now it is at the Indian Agricultural Research Institute in Delhi. The first documentation, with a useful bibliography, of major works published before the 20th century began, was by F.M. van der Wulp (1896), in his Catalogue of the Described Diptera from South Asia, another century-old celebration now. Wulp gave a useful 'Review of the Literature on Oriental Dipterology' (pp. 4–10), which cited the names of most dipterists who worked on Oriental flies, from Carolus Linnaeus to Major E.E. Austen, over a period of around 150 years. The Catalogue of the Diptera of the Oriental Region, by J.M.F. Bigot (1891–1892) was the first ever for this biogeographical region but was replete with errors and omissions, which Wulp painfully corrected in his own work. M. Datta & P. Parui (see Jairajpuri, 1991: 373-417) attempted a 'Historical Resumé' (pre-1900 to 1990) of Indian work on the Diptera, as well as an 'Estimation of Taxa' of most families in India, and were supported by similar 'state of the art' summaries by A.N.T. Joseph (on the Tipulidae), M. Datta (Simuliidae), C. Radhakrishnan (Tephritidae), S.K. Tandon (Agromyzidae) and P.T. Cherian (Chloropidae). The Zoological Survey of India dipterists identified approximately 6,093 species of true fly as "occurring in India" (see Jairajpuri, 1991: xxvi), which number they calculated to be 6.31% of the total world fauna, said by them to have 96,600 fly species (Ghorpadé, 1998: 3-5).

The 534 genera and 1,262 species of 64 families of Diptera known from the Western Ghats are given in Table I as catalogued by Delfinado & Hardy (1973, 1975, 1977), with some updates of a few of these families, mainly in the Western Ghats (cf. Ghorpadé 1998 also). I also maintain a list of the localities on the Western Ghats and the windward littoral coastline that together circumscribe the Western Ghats biogeographical sub-sub-area. This list includes both localities where I collected specimens and where others have collected and trapped flies, as documented in publications. The fold-out map included in Gamble & Fischer (1915–1936) also gives localities where botanical specimens were taken in southern India, especially within the erstwhile Madras Presidency.

Though many fly families have species that occur in both tropical and temperate parts of the Orient (the latter in the Baloch–Afghan, western and eastern Himalaya and northernmost Assam–Burma biogeographical divisions of this subcontinent, see Figure 1), some of these families are predominantly tropical or are temperate in their choice of environment. And this reflects their past history of evolution and diversification. The fly families presented here (which when compared with the total for this subcontinent), which have a low percentage of species in the Western Ghats, are almost all dominantly temperate in distribution. They occur (as currently known) only in preferred habitats in the northern mountain arcs of the Balochi, Afghan, Himalayan, northern Burmese and Naga–Arakan mountain ranges. The dipterofauna (and other biota) of the Western Ghats is predominantly tropical, with some subtropical and temperate elements (cf. Meher-Homji, 1979) inhabiting the higher altitudes of this mountain range. The sholah–grassland montane habitat is peculiar to the Western Ghats (perhaps also present on the higher aspects of the Eastern Droogs, the Central Highlands, and probably also the Garo–Khasi–Jaintia hills in the Assam–Burma area) and evidently contains a singular peninsular Indian and Ceylonese fauna and flora.

SUMMARY OF INSECT AND SPIDER DIVERSITY OCCURRING IN THE INDIAN SUBREGION

Some 15 years ago I had (Ghorpadé, 1997b) written a detailed paper on the status of insect diversity in the Indian subcontinent and it will be a repetition to go into those details again here. Similarly, Siliwal & Molur (2007: esp. 2552) have updated and published detailed information on our spiders. The Zoological Survey of India's "state of the art" report (Alfred *et al*., 1998) attempted a summary of research carried out on the insect fauna of India, but several statements made in that report require correction and a definitive assessment. This current paper computes a total of 7,801 species of Diptera in this subcontinent, while Alfred *et al*. mentioned just 6,100 species. Their focus was only on India, as a political unit, and does not lead to a fair assessment of the fauna that this subcontinent (= subregion) possesses. It was only a governmental documentation of this nation's fauna, for annual office "reports."

Table 2 gives a listing of the species numbers for each order of Insecta and Entognatha, taken from Alfred *et al*. (1998) and Ghorpadé (2010). It is unfortunate that even today there is no accurate checklist available on the Insecta of the Indian subcontinent, except for some taxa that have updated checklists or catalogues, and these are also mostly abstracted from world catalogues prepared and published by specialists abroad! The decreasing importance given to taxonomy today, and inadequate, miniscule funding for active sampling and inventory projects involving each taxon or geographical area, is shameful for a country and subcontinent as biodiverse as ours, involving not less than 10% of all of the biodiversity on this planet. It is also lamentable that India does not have even one modern, specialist natural history museum that parallels the several in western countries. The 'relics' of the British Empire in Calcutta (ZSI), New Delhi (IARI) and Dehra Dun (FRI) are poorly maintained, and mostly housing century-old specimens sampled before independence, because of a shortage of properly trained curatorial staff, and many primary types held in them (world heritage!) are in great danger of destruction through museum pests and fungal attack! The so-called natural history museums in New Delhi and in Mysore are impressive structures but are devoid of any worthwhile collections, except artistic displays for the rare visitor! What does this say about a nation that boasts of great commercial wealth but which cares but little for its natural wealth of plants and animals, bestowed on it by the evolutionary process? My disgust and genuine concern were made public in my editorial (Ghorpadé, 1997a) to a new journal on biodiversity that had to be terminated only because Indians generally have absolutely no interest in or education about wildlife and so the submission of standard papers gradually dried out!

Table 2 .

Inventory of known Indian flora and fauna (vide Zoological Survey of India, 1991, but updated by Ghorpadé)

PLANTAE Vascular Plants Lower Plants	15,000 Indian	(248,400 World) (101,700 World)
ANIMALIA	Indian	World
Protozoa	2,577	(31,250)
Porifera	519	(5,100)
Siphonophora	118	(180)
Sclerectinia	119	(7,000)
Ctenophora	10	(100)
Platyhelminthes	1,622	(17,500)
Turbellaria	47	(4,000)
Monogenea	295	(2,500)
Trematoda	750	(6,500)
Cestoda	530	(4,500)
Rotifera	310	(2,500)
Gastrotricha	88	(2,500)
Kinorhyncha	10	(100)
Nematoda	2,350	(25,000)
Acanthocephala	110	(800)
Sipuncula	38	(202)
Mollusca	5,042	(80,000)
Echiura	33	(127)
Annelida	1,093	(12,620)
Oligochaeta	585	(4,000)
Polychaeta	428	(8,000)
Hirudinea	59	(500)
Archiannelida	21	(120)
Arthropoda	57,525	(952,116)
Onychophora	1	(100)
Crustacea	2,970	(24,375)
Anostraca	72	(175)
Notostraca	11	(15)
Conchostraca	27	(180)
Cladocera	90	(400)
Ostracoda	120	(2,000)
Copepoda	540	(4,500)
Branchiura	4	(75)

Cirripedia	104	(750)
Isopoda	200	(4,000)
Amphipoda	143	(3,600)
Decapoda	1,535	(8,500)
Stomatopoda	124	(180)
Insecta	50,717	(839,052)
Thysanura	23	(1,250)
Diplura	16	(355)
Protura	20	(260)
Collembola	200	(5,000)
Ephemeroptera	106	(2,000)
Odonata	500	(5,000)
Plecoptera	113	(2,000)
Orthoptera	1,700	(20,000)
Phasmida	150	(2,500)
Dermaptera	350	(1,800)
Embiidina	33	(200)
Blattaria	186	(4,000)
Mantodea	161	(1,800)
Isoptera	300	(2,300)
Psocoptera	85	(3,000)
Phthiraptera	400	(3,000)
Hemiptera	6,500	(35,000)
Thysanoptera	693	(4,500)
Neuroptera	355	(5,500)
Coleoptera	15,500	(300,000)
Strepsiptera	18	(550)
Mecoptera	21	(500)
Siphonaptera	52	(2,380)
Diptera	6,100	(150,000)
Lepidoptera	15,000	(150,000)
Trichoptera	1,000	(7,000)
Hymenoptera	5,000	(115,000)
Diplopoda	162	(7,500)
Chilopoda	100	(3,000)
Xiphosura	2	(4)
Arachnida	3,574	(78,185)
Scorpionida	102	(1,500)
Pedipalpida	25	(85)
Solpugida	15	(900)
Opiliones	167	(1,600)
Pseudoscorpionida	100	(2,300)
Acari	1,915	(36,800)
Araneae	2,298	(40,000)
Phoronida	3	(11)

Bryozoa	170	(20,000)
Entoprocta	10	(60)
Brachiopoda	3	(300)
Chaetognatha	30	(100)
Echinodermata	765	(6,226)
Hemichordata	12	(118)
Chordata	4,894	(47,674)
Protochordata	116	(2,173)
Pisces	2,546	(21,723)
Amphibia	204	(5,145)
Reptilia	428	(5,375)
Aves	1,228	(9,026)
Mammalia	372	(4,232)
TOTAL FAUNA approx.	78,500	(1,217,622)

NOTE: The numbers in parentheses for each taxon are the total numbers of estimated or known world species.

Table 3.

Described species of 29 currently recognized orders of Insecta

Order	World Species	Indian species, approx. (known)	Remarks
Archaeognatha	504	50 (23) ca. 25 Indian spp. Unknown	
Zygentoma	527	50↑	↑
Ephemeroptera	3,046	300 (106)	ca. 200 unknown
Odonata	5,680	550 (500)	Synonymy undetected
Dermaptera	1,967	200 (350)	Synonymy undetected
Notoptera	39	3 (?)	[Grylloblattodea + Mantophasmatodea]
Plecoptera	3,497	300 (113)	ca. 200 unknown
Embiodea	458	40 (33)	ca. 15 unknown
Zoraptera	34	5? (?)	ca. 5 unknown
Phasmatodea	2,853	250 (150)	ca. 100 unknown
Orthoptera	23,616	2,000 (1,700)	ca. 300 unknown
Mantodea	2,384	200 (161)	ca. 40 unknown
Blattaria	4,565	400 (186)	ca. 200 unknown
Isoptera	2,864	250 (300)	Synonymy undetected
Psocoptera	5,574	550 (85)	ca. 450 unknown
Phthiraptera	5,024	500 (400)	ca. 100 unknown
Thysanoptera	5,749	550 (693)	Synonymy undetected
Hemiptera	100,428	10,000 (6,500)	ca. 3,500 unknown
Coleoptera	359,891	35,000 (15,500)	ca. 20,000 unknown
Raphidioptera	225	20↓	↓
Megaloptera	337	30 [355]	ca. 250 unknown

Neuroptera	5,704	550↑	↑
Hymenoptera	144,695	14,000 (5,000)	ca. 9,000 unknown
Mecoptera	681	60 (21)	ca. 40 unknown
Siphonaptera	2,048	200 (52)	ca. 150 unknown
Strepsiptera	603	60 (18)	ca. 40 unknown
Diptera	152,244	15,000 (6,100)	ca. 9,000 unknown
Trichoptera	12,868	1,200 (1,000)	ca. 200 unknown
Lepidoptera	156,793	15,000 (15,000)	Other world spp.. unknown ?
TOTAL	1,004,898	97,343 (54,346+ ?)	ca. 45,000 spp. unknown

NOTE: *Collembola, Diplura and Protura are now placed in the class Entognatha, of which probably about 11,000 world species (ca. 1,000 Indian possible?) are known so far. [For world numbers, vide Adler & Foottit (2009) Insect Biodiversity: Science and Society. Wiley-Blackwell. p. 3.].*

CONCLUSIONS ABOUT WESTERN GHATS AND INDIAN SUBCONTINENT DIPTERA

Of the 11 families known from the Indian subcontinent, but not yet confirmed in formal publications as occurring in the Western Ghats (see Table 1, Note), my personal collection includes specimens of all (sampled by me or other collectors) except the families Dixidae, Anisopodidae, Rhinophoridae, Megamerinidae (not searched for yet in my unsorted, uncurated samples, both dry, in papers, and wet, in alcohol) and, perhaps, Canacidae.

In closing this attempt at updating the database on the 64 families of true flies found so far in the Western Ghats (Sri Lanka has 71 families, and peninsular India–Ceylon has 75 families), it may be mentioned that from 825 to 950 more Diptera species could be occurring in the Western Ghats, which remain unknown or unrecorded so far (uncollected or unsorted and studied). The absolute maximum diversity of flies that could be occurring in the Western Ghats is estimated here to be about 2,000 species.

There are 22 other families of Diptera that have been found to occur in the Indian subregion (= subcontinent), which are mostly north temperate in their habitat choice, but some of them could occur at least on the crests and peaks of the Western Ghats or even elsewhere in Dravidia (peninsular India–Ceylon and the Central Highlands). These familes are Trichoceridae (3 genera and 21 species in the Indian subcontinent), Tanyderidae (1–3), Ptychopteridae (1–10), Nymphomyiidae (1–1), Deuterophlebiidae (1–2), Thaumaleidae (1–15) [all Nematocera]; Coenomyiidae (1–2), Lonchopteridae (1–12) [Brachycera]; and Cypselosomatidae (1–2), Strongylophthalmyiidae (1–7), Megamerinidae (1–2), Nothybidae (1–1), Dryomyzidae (1–1), Piophilidae (1–21), Teratomyzidae (1–1), Clusiidae (9–15), Anthomyzidae (1–1), Odiniidae (1–1), Carnidae (2–4), Diastatidae (2–6), Heleomyzidae (1–1) and Scathophagidae (6–7) [all Cyclorrhapha].

Six other families, known from the Sino–Malayan and Papuan–Pacific subregions of the Oriental Region, located further east, have not yet been recorded from the Indian sub-region. These families are Pachyneuridae (1 genus and 1 species known from the Oriental Region) [Nematocera]; Apioceridae (1–1) [Brachycera]; and Pseudopomyzidae (1–1), Chyromyiidae (2–3), Heteromyzidae (1–2) and Tethinidae (3–7) [Cyclorrhapha].

Incidentally, the fauna of the island of Ceylon (which was once, or several times, connected to the Indian mainland in geological history, see Ripley, 1949) perhaps has 25–30% of the biota of this entire mountain range and is currently better sampled and studied than the fauna of the Western Ghats, in southern India. A 11-year duration project of the Smithsonian Institution, Washington, DC (U.S.A.), where I was a Postdoctoral Fellow in 1982 and 1983, surveyed and sampled the Ceylonese insect fauna under the supervision of the late Karl Krombein. The collection is still being worked on by international specialists (Krombein, 1981 et seq.). Museum specialists in some other countries (such as Switzerland and Sweden) have also made their own surveys of Sri Lankan insects. A similar international project, running at least for a decade, and involving collaboration with several countries' museums (institutions) and working specialists, is urgently required here if our entomofauna is to be properly surveyed and researched for valuable collections and databases. Speaking of the Indian sub-region (subcontinent) as a whole, the 7,000 to 8,000 currently known and named species could be swelled by the discovery of at least another 5,000 unrecorded species, making a total of about 12,500 Indian sub-region Diptera in all. But I estimate that, a total of some 15,000 species of Diptera could actually be flying in the Indian subcontinent, as may be found after our forest canopies are also well sampled. The Diptera species diversity estimate of peninsular India–Ceylon and the Central Highlands ('Dravidia', together) could be anything between 20,000 and 40,000 species of true flystet. However, if the Western Ghats have only about 15% of the total Indian fauna, then there should be at least five or six more such hotspots in our sub-region, holding the remaining 85% of our total fauna. But, only the western and eastern Himalaya and the Andaman–Nicobar islands have been so identified, leaving the other areas (and habitats) unmentioned and underrated! Something is wrong somewhere…

KNOWLEDGE GAPS

From my perspective, seven major gaps in our knowledge of true flies (Diptera) of the Western Ghats exist; they may apply similarly to other faunal taxa:

1. Biogeographic distributional ranges of taxa need to be fully mapped.
2. Phenology or seasonal occurrence and local movements ('migration') of species to be determined.
3. Host plant, prey, saprophytic food, *etc.*, of species to be investigated.
4. Life-histories and bioecology, including pollination efficiency of flower visitors, to be studied.
5. Parasitoids, parasites and predators of fly species to be documented.
6. Economic significance for humans, beneficial or harmful, to be analysed.
7. Survey and sampling of remaining undisturbed habitats for species diversity is a major and primary need and requires to be undertaken in urgency, before these surviving pristine habitats fall to 'development', population expansion, and other human exploitation.

In brief, therefore, we need to survey and inventory the Diptera in the Western Ghats and intensively study their biology and ecology in this mountain range. Other needs of our Diptera research and some 'working plan' suggestions were given by me earlier (see Ghorpadé, 1998: 5–6). Alfred *et al*. (1998: 485) had named only 19 specialist dipterists, including myself, currently researching Indian subcontinent flies as possible sources for help with identifications and information on our flies. I welcome any offers of joint research on Indian Diptera taxa or requests for their study or identification by specialists.

A major 'gap' in our knowledge of the biodiversity of the Western Ghats is the comparative lack of planned surveys done in the northern (longest) section, *i.e.* from the Surat Dangs to the Kalinadi River, in Gujarat, Daman, Dadra and Nagar Haveli, Maharashtra and Goa. Sālim Ali carried out bird surveys in this section, and ornithological databases do exist, as do some databases on this section's butterflies (vide infra), but many of these ghat areas, called Sahyadris in Maharashtra, and especially the west–east spurs extending from the Western Ghats crest line eastward onto and into the Deccan Plateau, are hardly known for what may be 'source areas' for the certainly diminished diversity of the Sahyadris, caused by fissured volcanic eruptions that destroyed most of the evolved and adapted biota and created a new geology, leading to a stunted, depauperate, flora here. My limited surveys of the Sahyadris and the Dangs have actually turned up quite a few surprises in Diptera species and genera here, as well as in the avifauna. This northern section of the Western Ghats also has 'narrow' endemics in birds, like the now un-lumped Sykes' or Vigors' Sunbird (better called Sahyadris Sunbird, *Aethopyga vigorsii*), and the still lumped Bombay Babbler [*Turdoides (striatus) somervillei*], to cite glaring examples, which should be, or are, present in other groups also, if distributional patterns and even 'minor' morphological differences are tested for congruence. Prakash Gole (1998) edited a useful special issue on the birds, snakes, mammals, turtles, lizards and rare and endemic plants of the Sahyadris, which is a starting point for further studies on this peculiar, little-known, northern section of the Western Ghats.

It may be mentioned here that our joint paper (Pearson & Ghorpadé, 1989), on the biogeography of tiger beetles (Coleoptera: Cicindelidae) here now needs more data based on further field sampling in still poorly surveyed biogeographic divisions of this subcontinent (Andaman–Nicobar islands, Assam–Burma, Central Highlands, Deccan Plateau, Eastern Droogs–Carnatic), for a better, thorough analysis based on more complete databases and a refined taxonomy using an 'omnispective' approach (cf. Blackwelder, 1964; Borgmeier, 1957).

Unless a holistic, well-documented analysis is initiated by biologists to study nature and build factual databases of its floral and faunal diversity together, only chipping away at its 'bits-and-pieces', by odd taxon or subject specialists, who are unable to coordinate their research findings on a biogeographical, if not global scale (certainly not political), is hardly going to enable us to understand and then protect and restore our wilderness heritage. The whole is certainly greater and more complex than the sum of its parts, and it is critical to our understanding of nature, its still untapped resources and how we can fit into her natural balance.

Hence, the Western Ghats diversity can not be fathomed in isolation from that of the Deccan Plateau and the Eastern Droogs–Carnatic sub-areas of the peninsular India–Ceylon biogeographical area, at least. Similarly, social insects and their lives are incomprehensible if studied in seclusion. A minimal 'birds–butterflies–botany" (vertebrates, invertebrates, plants) approach is recommended here, especially as an integrated group activity, involving specialist scientists (taxonomists) interacting with tribal and 'grassroots' locals in the field, whether in natural wildernesses or agro-ecosystems, supported by postgraduate students.

Our inventory of the natural genetic resources that have evolved in this subcontinent is very far from being even half–complete, and our claims of 'endemic' species are flawed, with little scientific backup, based on poor data. Gadgil's (1996a) proposed LIFESCAPE project deserves wholesale, nationwide collaboration of biosystematists, field biologists and students (cf. Gadgil, 1996b), who need to be provided with adequate funding (actually easily affordable now!) and logistical support by government departments and national/international funding agencies. What we desperately require, sooner than later, are long-term scientific explorations (like those made in the last two centuries, by pioneering, indefatigable, foreign explorers!) to sample our biodiversity in the rapidly disappearing undisturbed or minimally human-encroached habitats, as well as make detailed inventories of museum collections of biological material from the Indian subcontinent, both in institutions of this country and those abroad.

Unless we know what we possess and publicize this natural heritage of ours, no government or private individual/ institution is going to become aware of the real value of the natural treasures and their wild inhabitants we still have. And these also seriously thinking about carefully restoring our artificial environments (some man-made "wastelands") in rural and urban areas, especially in the plantation properties on the Western Ghats (some on the Eastern Droogs) as well.

CONCLUSIONS ON WESTERN GHATS BIODIVERSITY AND CONSERVATION

Specific lacunae in our knowledge and understanding of each fly family in the Western Ghats have been indicated in the brief synopsis given for each family above (q.v.). In connection with this all-important 'human selection' decision of conservation hotspots (see Collar, 1997; Quammen, 1996), I wish to make the following studied observations with particular reference to peninsular India–Ceylon and its sole hotspot, identified for biodiversity protection in southern India—the Western Ghats. Because this volume also covers conservation of the arthropod diversity of the Indian sub-region, it seems important and appropriate to deal a little seriously with this aspect and go into other available databases on the biotas. As I have quoted in my recent revision of the syrphid genus *Agnisyrphus* (Ghorpadé, 2007: 25), Vane-Wright (1993) citing May (1990), had emphasized that 'in some very real sense, taxonomy may affect the destiny of species'. So we need also to be made aware of the species or habitats we ignore or undervalue now, which then are destined to a 'slow death', being bereft of conservation focus!

First, though the Western Ghats have been a popular focus of field biologists owing to their abundant habitats and comparatively rich biota, we do not know and understand much about this recent geological–botanical–zoological ecosystem and its entire biodiversity. The widely inconsistent percentages of endemic species of different taxa (*e.g.* flowering plants, 38% (Nayar, 1994); land snails, 75% (Aravind et al., 2005); amphibians, 78%, reptiles, 62%, mammals, 12%, birds, 4% (all Kunte, unpubl. data , but vide infra); dragonflies and damselflies, 38% (Subramanian & Sivaramakrishnan, 2002)) and the variations among several families of Diptera, as cited in this paper, are proof of insufficient research and study, based on inefficient sampling and observation in the remaining undisturbed habitats still existing in this mountain range, from the Dangs to the Ceylonese highlands. For example, the poor (4%) endemism, as believed, of birds in the Western Ghats is a complication created out of the 'lumping' of distinct, allopatric (even if externally minutely distinguishable) populations that were separated earlier as distinct species by both resident and overseas-based foreign taxonomists (mainly European) during the British Raj period through careful, painstaking, field and museum research. In fact, Myers *et al.* (see Nature, 24 February 2000), gave figures of 8% for bird endemism (double!) in the Western Ghats, 27% for mammals, 46% for plants, 62% for reptiles and 79% for amphibians! This embarrassing muddle and mix-up came up after the formal recognition of the subspecies (or 'race') as a nomenclatural category below the species, especially in ornithology. I am convinced that the species still is the lowest useable, relevant, nomenclatural category that identifies reproductively isolated (mostly through allopatry or ecological niche choice—geographical species concept) populations that are bound together by a unique life-cycle that keeps them reproductively and phylogenetically separate in life even from their nearest 'relations' or sibling species (see Ghorpadé, 2002).

BIRD DIVERSITY

My own analysis of the Western Ghats avifauna, made some 10 years ago (unpubl. data), made me list some 60 bird species (11%) as 'R-E-D' (restricted, endemic or disjunct). Species recognized as restricted are those that, though certainly evolved and endemic in the Western Ghats sub-area, also wander or sometimes even breed outside this hill range. Examples are the Yellow-browed Bulbul *(Iole indica)* and the Malabar Whistling Thrush *(Myophonus horsfieldii)*. Endemics are of course intimately connected to the Western Ghats and incapable of surviving elsewhere outside their special habitat range where they evolved, like the Small Sunbird *(Leptocoma minima)*, Great Pied Hornbill (*Buceros bicornis*–the north-east Indian population is perhaps more correctly a distinct species, B. homrai; unpublished data), Black-and-Orange Flycatcher (Ficedula nigrorufa) and others. But the interesting and highly important question is about 'species' that are disjunct. My own taxonomic training and experience leads me to separate these widely (or even less widely) distinct taxa as disjunct species, not as races or 'subspecies'. Karanth (2003) raised this intriguing point in a well drafted paper, and Rasmussen (2005) summarized the 'conservation implications' of such taxonomic decisions in an appropriately titled recent paper. In the Western Ghats, such disjunct and 'lumped' species are, for example, the Malabar Pied Hornbill (*Anthracoceros coronatus*), Crested Goshawk (*Accipiter trivirgatus*) and Large Wood Shrike (*Tephrodornis gularis)*, the latter having now been 'split', correctly, into two distinct species, the Malabar Wood Shrike (*T. sylvicola*) being the endemic Western Ghats species (see also others unlumped in Rasmussen (2005), like the Ruby-throated Bulbul, *Pycnonotus gularis*). Hence, unless research on the taxonomy of our unique and rich biota is adequately funded and necessary permissions given by the Ministry of Environment and Forests–the recent ban on sampling in Protected Areas, for bona fide scientists, without a 'permit' is a seriously retrograde Parliament decision–to both native and foreign specialists, we will be unable to fully know what the endemic quotient of our biodiversity (each animal and plant group) is. Hence, before we are shown what we need to protect as our unique heritage, industrial and consumer greed will destroy the less than 3% of natural ecosystems still surviving that have evolved in this subcontinent and that are our responsibility to protect, preserve and study. The late M. Krishnan wrote in despair, a little before he died, a small note titled "India–A Wildlifer's Apprehensions", published in the Bombay Natural History Society's now bimonthly bulletin, Hornbill (see also extract in Indian Journal of Biodiversity, 1: 197–199; 1997), giving his 'convictions of a lifetime on our country'. He lamented, rightly, that "If we cannot meet the needs of our peoples with 90% of the land then there is something seriously wrong with our administrative efficiency"!

BUTTERFLY DIVERSITY

Having looked at the ornithology of the Western Ghats in a synoptic manner, I would now like to focus on the most popular and best studied (and therefore known) group of the overwhelmingly dominant animals on earth (which are the insects; see Ghorpadé, 1986b, 1997b for summaries)–meaning the butterflies (*Lepidoptera*: Rhopalocera; see DeVries, 2001: 559). Harish Gaonkar is undoubtedly the most experienced current specialist scientist on Indian butterflies, and his comprehension of the database on these beautiful insects is vast and impressive. I spent almost two years (1995–1996) assisting him in the documentation of his report (Gaonkar, 1996) on the Western Ghats butterflies and can vouch for his immense, but sadly still unpublished, information, ranging from accurate taxonomy to biology, habitats, history and names and much more. He wrote (Gaonkar, 1996: 7): 'A unique feature of the Western Ghats is that, an area with rich butterfly diversity is also an area that is rich in all other faunal and floral diversity'. He also opined that butterflies are better known than any other faunal group, except perhaps birds, and hoped that his study of the butterflies of the Western Ghats would 'be consulted as a model by researchers using other animal and plant groups for biodiversity assessment'. Gaonkar identified 16,823 or so butterfly species as so far named and described from the world and estimated around 1,500 species to exist in the Indian subcontinent.

I, however, believe that, as in birds (vide supra), there are almost twice the actual number of existing species of butterfly (as were documented before this subspecies concept was ushered in at the turn of the 19th century) and that precise distributional ranges and endemic percentages are far from known. Hence, I have consciously chosen not to attempt any wild guesses at the percentage endemism of true flies here. They must be almost completely researched and documented. Gaonkar's list of Western Ghats butterfly species and recent updates (Kunte, unpubl. data) give a total of 333 species in the Western Ghats, placed in 165 genera, of which 63 (19%) are endemic. Gaonkar listed 243 species (21 endemic, 9%) in 127 genera from the island of Ceylon. But, as I consider biogeographically and evohistorically more appropriate (see notes in Ghorpadé, 2007: 14-25), this mountain range must be looked at in its complete geographical entirety, including the Ceylonese highlands biota as a fourth section of these ghats. This way, the entire stretch of these peninsular India–Ceylon highlands possesses a total of 359 butterfly species (84 endemic, 23%) belonging to 166 genera.

If even this percentage is a little lower than actual value, according to my taxonomic and scientific reasoning; incorrect lumping of distinct, allopatric, species is the reason. The numbers and percentages for birds are highly skewed and need immediate taxonomic investigation and revisions by expert systematic ornithologists. Distinct endemic species of these ghats that are currently lumped with distantly allopatric species found in North-east India, or the eastern Central Highlands, may therefore be unfortunately and incorrectly ignored in our conservation evaluation! In butterflies also, the R-E-D species need closer study and, like the recently rediscovered Spot Puffin in the Western Ghats (*Appias lalage*), after 100 years (Nalini & Lomov, 1996; Soubadra Devy, 1998; Kunte, unpubl. data), hugely disjunct from other known populations in North-east India (!; taxonomy needs investigation), many more such little-collected and apparently disjunct species (treated as 'subspecies') need to be evaluated for their correct taxonomic status and 'un-lumped' forthwith. So, even for very popular and relatively well-studied groups such as flowering plants (almost 50–60% are endemic here, in reality!), birds and butterflies, the knowledge situation is not at all satisfactory. So one can imagine the status for the majority of other animal groups, such as the true flies! When is this basic in vivo research and in vitro documentation going to happen? After the jungles are all gone?

TRUE FLY DIVERSITY

The database available on our Diptera has been presented in this paper. It originates mainly from the Catalog of Oriental Diptera (Delfinado & Hardy, 1973, 1975, 1977) published three decades ago. I have included updates of a few families (*e.g.* Syrphidae, Asilidae, Sarcophagidae) but need more time and funding for assistance and mobility to complete a thorough revised catalogue (or at least an annotated checklist) of the true flies of the Indian subcontinent. The Western Ghats are estimated to possess anything from 40% to 50% (only, and not more, as is generally believed–hence this hotspot labeling) of the Diptera species known so far from the peninsular India–Ceylon biogeographical area. And the Western Ghats possibly have from 15% to maximally 25% of species of the true flies of the entire Indian sub-region. So, it may be safe to presume that the Western Ghats have approximately three fifths to two thirds or less of the peninsular India–Ceylon biota and up to one fourth of the Indian subcontinent flora and fauna. These percentages should also apply to all other taxa except for specially adapted groups (these will have higher percentages) or those preferring more arid habitats (these will have lower percentages). With regard to the birds and butterflies (except for the lumping syndrome and resulting skewed figures), the island of Ceylon and the Western Ghats in peninsular India are perhaps the best known geographical areas in the Indian subcontinent. The Eastern Droogs–Carnatic and Deccan Plateau biota are still poorly surveyed and documented!

SOURCE AREAS

From the initial invasion of the newly uplifted and still rising(?) Western Ghats (by faulting), more new species evolved by the species extant then adapting to the higher altitudes as and when microniches opened up in geological time over the past 50 million years or more. The lower leeward foothills and slopes of the Western Ghats still have this ancient, drier forest and scrub habitat flora and fauna, which are a feature of the ancient Eastern Droogs. It is hence argued that even these Eastern Droogs and their biota form other, dissected, hotspots that must also be protected and conserved, as they were fundamental source areas and gene pools for the colonization of the young Western Ghats niches opening up. In fact, the still fairly rich diversity-possessing Eastern Droogs (Biligirirangan, Kollimalai, Pachchamalai, Bodamalai, Kalrayan, Chitteri, Melagiri, Shevaroy, Javadi, Bannerghatta, Nandi, Devarayadurga, Sandur, Horsley, Palkonda–Seshachalam, Nallamala–Velikonda, Lankamala, Erramala, etc., cf. Legris & Meher-Homji, 1977), are examples of these other hotspots, even if they are considered minor and are sadly ignored by conservationists! Even the Deccan Plateau has some fairly well-vegetated hill ranges, such as Balaghat, Chandor, Ajanta, Nirmal, Jalna, Badami, Homnabad, Kakatiya, Amrabad, Medak and Satmala, which have hardly been explored for their biota.

The Central Highlands biogeographical area (see Figs 1, 2; also Forsyth, 1889) is a huge, ancient portion of the once Greater Indian Plate, which remains poorly surveyed, sampled and documented (Rudyard Kipling's classic Jungle Book was based on a location in this area). The highlands in eastern Madhya Pradesh (now Bastar and Chhattisgarh), north-eastern Andhra Pradesh (Northern Circars of yore), Orissa (Kalinga) and southern Bihar (now Jharkhand) have biota that show phylogenetic links with what now occur on the Himalaya (at least in the eastern Himalaya) and, in my opinion, are crying out for such recognition and further research on them! The Garo–Khasi–Jaintia hills, in Megahalaya state, may also be an ancient Gondwanaland 'splinter', now separated from Dravidia by the recently formed Ganges–Brahmaputra river basin delta and are possibly another source area for the new eastern Himalayan biota. The hill ranges of the Central Highlands that need more surveying and sampling for biota are the Aravalli, Mandav (in Kathiawar peninsula), Vindhya, Satpura, Mahadeo, Bhanrer, Kaimur, Maikal, Chhota Nagpur, Golcondah ('Vizag Ghats'), Gawilgarh and Wainganga. The papers by Legris & Meher-Homji (1977) and Meher-Homji (1979) are good starting points, along with the fine compilation of Mani (1974), for understanding what lies unknown in Dravidia (= Central Highlands + peninsular India–Ceylon), which is what is left, above sea level, of the Greater Indian Plate, at this point of time. The Andaman Islands (if not the Nicobars) are a further question mark regarding the true affiliation of their biota, and these may also have been part of the Gondwanan split and northward land drift across what is now the Indian Ocean.

CONSERVATION AND RESTORATION

I do not understand the 'conservation value' judgement norms currently followed but can recommend that only by protecting (and restoring) all remaining pristine and minimally disturbed habitats by legal and military force can their biota be automatically saved for posterity. But the optimal sizes of these protected and restored habitats (PRHs), which may be different for insects from those for larger animal groups, are critical for allowing their wild inhabitants' normal life-cycles and maintaining policed corridors between adjacent PRHs for animal range continuity.

When the faunistics of other abundant florally diverse habitats in this sub-region become known (e.g. Assam–Burma, western and eastern Himalaya, eastern Central Highlands, Eastern Droogs–Carnatic, Andaman–Nicobar islands: see maps, Figs. 1, 2), the relative richness percentages of the Western Ghats flies, butterflies, birds and flowering plants may decrease. This leads to my final observation about the value of biogeography and evohistory and the additional importance of also protecting currently less rich but more ancient source areas. This present, recent abundance of birds in the Western Ghats is mainly of species adapted to wet forest habitats and ecosystems. Don't we need to preserve other distinct, specially evolved and adapted biota in less rich, dry-zone and semi-arid habitats? Are only rice, sugarcane, coffee and cocoa important for mankind and not cotton, millets, chillies and custard apple, for example? My strong belief is that the currently scientifically skewed 'valuation' of biodiversity and the resultant incorrect weightage given to these few hotspots (what about 'coldspots' and life-giving glaciers, and their high altitude ecosystems, which feed streams and rivers?) need to be reconsidered and refined. The late Dr. Mani carried out much field work on high-altitude entomology in the western Himalaya (see Mani, 1974) and wrote some much-consulted books on this special and poorly studied science.

Papers such as those of Williams et al. (1996) need to be considered while making conservation decisions on wilderness habitats. As these authors concluded (p. 168), ". . . identification of better methods of area selection and their continuing refinement should aid projects dealing with other goals and with other, less well-known groups." They also brought in the value of 'complementary areas'–similar to what I term 'source areas' in this subcontinent's context–apart from these so-called hotspots. An article in the newspaper New York Times (28 September 1993) reported on the finding of a British team of ecologists that "found that many hot spots, despite the profusion of species, did not contain any rare species. . ." E.O. Wilson is quoted as saying that "because of fragmentation different types of conservation reserves in the United States are likely, as the British study found, to be hotspots for different types of organisms. Much more needs to be known about the 'congruence' of species groups and the ecology and population biology of rare species in different areas around the world." Wilson concluded that "the original approach of identifying hotspots and making conservation decisions based on them is basically sound; we just need to refine it a great deal".

Immediate international 'armies' (wilderness protection forces) need to be created across national political boundaries (these are of no consequence to any wild plant or animal!), just as the Interpol was coordinated to bring international criminals to justice. Destruction of natural resources created by evolution, long before humans evolved, and now irresponsibly over-utilized by them, is a crime greater than anything relating to man's money or his murder, and, unless forcefully checked and stopped, will result in human suffering on a large scale, if not extinction.

More than focusing on animals (mostly larger and attractive species), it is absolutely imperative that conservation (What about restoration? And that too of pre-existing native flora, not just 'afforestation', with commercially selected exotic, fruit or timber trees!) executives, in governments or NGOs, make protection and re-planting of primary native vegetation their chief aim. Meher-Homji (1994), more than a decade ago, documented the alarming situation with the remaining percentages of the several 'series' under the four major forest types that occur in peninsular India–Ceylon: evergreen, semi-evergreen, deciduous and thorn. Our priorities are unfortunately topsy-turvy, short-sighted, commercially influenced and suicidal. Time is short, and our unchecked human population growth and this clearly unsustainable commerce-based and consumer-backed 'development dream' spell doom for us and maybe most other life on earth!

The current paranoia and concern about 'global warming' needs to be properly understood and tackled. In my opinion, it is the massive deforestation that earth has undergone in the last 200 years that is mainly increasing the carbon dioxide content in the atmosphere and influencing accelerated, cumulative, warming as a consequence of logging, burning and clearing. Emissions from 'greenhouse gases' can only be secondary 'polluters'. Afforestation of cleared or denuded forest areas, where agriculture is impractical or economically ill-advised, is the way to bring climatic harmony back on earth, especially if humans control their birth rate within the 'carrying capacity' of living habitations and their sustainable resources. This western, 'American', consumerist, industrially focused lifestyle is what is absolutely unsustainable, and following it for individual (or national) monetary superiority (psychological), or easy living, will be suicidal and obviously impractial in the long run. Hespenheide (2001: 357) interestingly, and thankfully (!), made the same judgement recently, opining that "Widespread beetle extinction over the next century is especially likely in the face of accelerating environmental destruction of the richest sites in the tropics to accommodate growing human populations and, even more significantly, to maintain Western European and North American standards of living." The Old World and tribal lifestyle, which was monitored by Nature's graciousness and goodwill, will have to be quickly promoted as an alternative, original, human lifestyle that can and will have to be made sustainable for us and the wildlife (plants also!) that shares this only living planet with us! It is a sustainable lifestyle and not 'development' that we supposedly intelligent humans must aim for in the future before we plunder Nature's wealth to its 'bones and roots' and leave us thirsty, hungry and, finally, as 'dead as a dodo'!

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ROLE OF BUTTERFLY GARDENS IN PROMOTING BIODIVERSITY CONSERVATION AND ECOTOURISM

George Mathew[1], **Elizabeth George**[2] **and Mary Anto**[1]

1. Division of Forest Health, Kerala Forest Research Institute, Peechi 680 653, Kerala, India.

2. Department of Horticulture, GKVK, University of Agricultural Sciences, Bangalore

email : gmathewkfrie@gmail.com

ABSTRACT

The role of butterfly gardens as conservation-cum-ecotourism ventures was evaluated in a model garden established in a 0.5 ha patch of degraded moist deciduous forest in the KFRI Campus at Peechi (Kerala, India). As a result of the introduction of host plants and habitat management, there was a tremendous increase in the butterfly population, with 4509 sightings of butterflies belonging to 43 species during the first half of the project (after the first 15 months) and 5993 sightings of butterflies belonging to 50 species during the second half (from the 16th month to the 30th month). Altogether, 10,502 sightings of butterflies belonging to 56 species were recorded during the 30-month study period. These included nine species that are endemic to the Western Ghats and 10 species having a protected status under the Indian Wildlife Act, compared with about a dozen species recorded from the area before the garden was set up. The butterfly garden set up at Peechi formed a major tourist attraction, with over 11,483 visitors during the period from April 2004 to March 2009, not including the number of visitors at the facility during the Open House event, which drew several thousand visitors.

INTRODUCTION

The establishment of butterfly gardens helps maximize butterfly diversity and abundance in urban and suburban areas, conserving species that might otherwise become rare or even disappear. It was in this context that the present investigations on the in situ conservation of butterflies through butterfly gardening were undertaken and a prototype garden was set up in a 0.5 ha patch of degraded forest in the KFRI (Kerala Forest Research Institute) campus at Peechi, mainly to standardize methodologies for establishing such gardens in the conditions prevailing in Kerala (Mathew, 2001).

MATERIALS AND METHODS

SITE SELECTION

The site selected for establishing the garden was a patch of highly degraded moist deciduous forest within the KFRI campus, which has been under protection since 1975. The terrain is undulating and hilly in nature, with steep slopes and a more or less plain ridge. The vegetation of this area included a few *Bombax malabaricum, Ailanthus triphysa, Tectona grandis, Grewia tiliaefolia* and *Terminalia bellerica* trees along the slopes and ground vegetation, comprising mostly weeds such as *Lantana camara* and *Chromolaena odoratum.*

LANDSCAPING AND INTRODUCTION OF HOST PLANTS TO RECREATE BUTTERFLY HABITATS

The basic design of the garden was prepared based on the terrain and geographical features of the area as well as the behavioural characteristics of butterflies since foraging and breeding are the important activities of butterflies.

As far as possible, the existing vegetation was retained, and native plants were preferred for introduction. Selection of host plants for introduction was based on data already available on the host plant preferences of various butterflies present in the area. The plants were introduced in a phased manner. Data pertaining to the butterfly host plants already present in the study area and those subsequently introduced are given in Appendix 1.

Since environmental education of the public was the main target of this programme, care was taken to make an exhibit of butterflies in a special area of the garden. For this, an area along the entrance was developed as the 'Butterfly Exhibit Area' around a circular canal 0.5 m wide and 60 cm deep (Figs. 1 & 2). This area was planted with butterfly aggregation plants such as *Heliotropium keralense* and *Crotalaria retusa* to facilitate roosting of danaid butterflies. Other plants introduced in this area included *Cycas*, ornamental palms, *Cuphea, Cassia tora, Jatropha podogirica, Kalanchoe blossfieldiana* and *K. pinnata. The remaining area of the garden was planted with plants such as Wattakaka volubilis, Thottea siliquosa, Tylophora indica, T. camosa, Asclepias sp., Calotropis giganteum, Carissa carandas, Ruta graveolens, Aegle marmelos, Albizia lebbeck, Cassia* spp., *Citrus* spp., *Murraya koenigii, Mussaenda luteola, M. laxa, Ixora* spp., *Kalanchoe blossfieldiana* and *K. pinnata*. All these species are known to support a variety of lycaenid, pierid, satyrid and nymphalid butterflies.

Figure 1.

View of butterfly exhibit area with the circular canal prior to introduction of host plants.

Figure 2.

A view of the butterfly exhibit area after landscaping and introduction of host plants.

The tall trees present in the garden offered a very good habitat for many swift-flying butterflies, especially papilionids, and the area where they were located was developed into a butterfly forage area (Figs. 3 & 4) through the introduction of host plants suitable for large butterflies. For this, nectar plants such as *Clerodendrum capitatum, Cassia* spp. and *Lantana camara* and larval food plants such as *Michelia champaca* (food plant of *Graphium doson* and *G. agamemnon*), *Zinnamom zeylanicum* (food plant of Chilasa clytia), *Zanthoxylum rhetsa* (food plant of *Papilio helenus* and *P. crino*), *Aegle marmelos* (food plant of *Papilio demoleus* and *P. polytes*) and *Citrus aurantia* (food plant of *Papilio polytes* and *P. polymnestor*) were introduced. Care was also taken to retain the ground vegetation and to leave the accumulated dry leaves and other debris undisturbed in order to offer suitable habitats for satyrid butterflies. Thickets of palms, *Heliconia* and ornamental varieties of *Musa* were introduced to develop dense vegetation conducive to the breeding of satyrid butterflies (Mathew, 2001).

The garden was fenced using pre-fabricated steel frames over which creepers such as *Passiflora edulis*, *Aristolochia indica*, *Ipomoea* sp. and *Wattakaka volubilis* were grown. Along the sides of the nature trail as well as in open areas present in the garden, nectar plants such as *Ixora* spp., *Cassia* spp., *Allamanda cathartica*, *Hibiscus rosa-sinensis*, *Cuphea miniata*, *Zinnia haageana*, Marigold, *Clerodendrum capitatum* and *Lantana camara* were introduced. Because of the mixed assemblage of a variety of larval and adult host plants, a number of butterflies belonging to diverse groups became general visitors to this area.

MONITORING AND RECORDING BUTTERFLY POPULATION TRENDS

In order to evaluate the effect of habitat enrichment, regular monitoring of the fauna was carried out by making daily transect counts and recording the numbers, for the entire study period, from June 1998 to November 2000, along a 175 m long, 1.5 m wide line transect traversing the garden. Along this transect, two fixed locations were selected for sampling—one in the garden area and the other in the area containing wild nectar sources. A 10-minute visual survey was done during each sampling period. Two transect counts, *viz*., a forenoon count, between 10.30 hrs and 11.30 hrs, and an afternoon count, between 14.30 hrs and 15.30 hrs were made at the two locations (Yamamoto, 1975).

ANALYSIS OF DATA

Seasonal index

For comparing butterfly population trends, the seasonal index for each month was calculated using the following formula:

$$\text{Seasonal index} = \frac{\text{Month-wise mean}}{\text{Overall mean}} \times 100,$$

where, the month-wise mean is the mean number of butterflies for a given family sighted during a month and the overall mean is the mean of all the month-wise means. By calculating the seasonal index, it was possible to interpret the mean/percentage of occurrence of butterflies in a given month in relation to the overall mean of monthly sightings.

2.4.2. Role of butterfly gardens in promoting ecotourism: Trends in visitor turnout

In order to evaluate the role of butterfly gardens in promoting ecotourism, the trends in visitation with respect to season, geographical region and educational background of visitors were recorded and analysed.

RESULTS

BUTTERFLY FAUNA

Prior to landscaping and introduction of host plants, about a dozen species were recorded in the study area, most of which were represented by only a few individuals. Following the introduction of appropriate larval and adult host plants, there was a sharp increase in the number of butterflies visiting the area, in terms of both individuals and species. During the first half of this study (after the first 15 months), there were 4509 sightings of individuals belonging to 43 species, and in the second half (from the 16th month to the 30th month), 5993 sightings of individuals belonging to 50 species were recorded (Appendix 2). After 30 months of monitoring, a total of 10,502 sightings of individuals belonging to 56 species were recorded. Continuous monitoring has shown a steady increase in the number of sightings, with 73 species of butterfly being recorded in the study area, including eight species that are Western Ghats endemics and 10 species that have a protected status under the Wildlife (Protection) Act, Government of India (GoI, 1972).

Figure 3.

View of butterfly forage area before establishment of host plants

Figure 4.

View of butterfly forage area after establishment of host plants

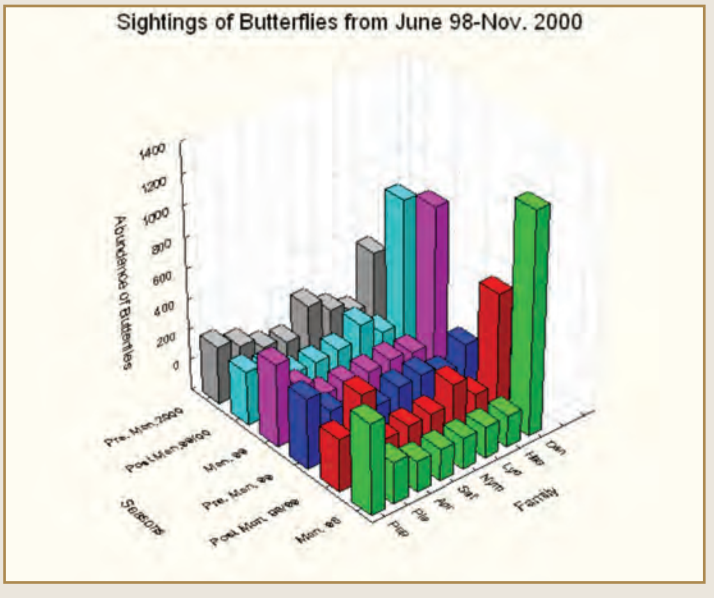
Figure 5.

Aggregation of Blue Tiger on Crotalaria retusa in the Butterfly Garden at KFRI

SEASONAL POPULATION TRENDS OF BUTTERFLIES IN THE GARDEN

Data generated by pooling the sightings of all groups of butterflies during the period from June 1998 to May 2000 showed that the families Papilionidae, Pieridae and Danaidae, which were able to efficiently exploit the available resources, had the highest numbers in the garden (Figs. 5 & 6). It was also observed that while several butterflies of the families Papilionidae and Pieridae showed a more or less continuous population trend for most part of the year, with a resident population in the study area, others of the families Danaidae, Lycaenidae, Satyridae, Nymphalidae and Hesperiidae were mostly seasonal. *Chilasa clytia* (Papilionidae); *Acraea violae* (Acraeidae); *Elymnias caudata* (Satyridae); *Talicada nyseus*, *Rathinda amor* (Lycaenidae); *Parantica aglea*, *Tirumala s eptentrionis* (Danaidae); and *Gangara thyrsis* (Hesperiidae) were some of the butterflies that have colonized the area following habitat enrichment and host plant introduction.

Figure 6.



Overall seasonal population trends of various groups of butterflies in the garden.

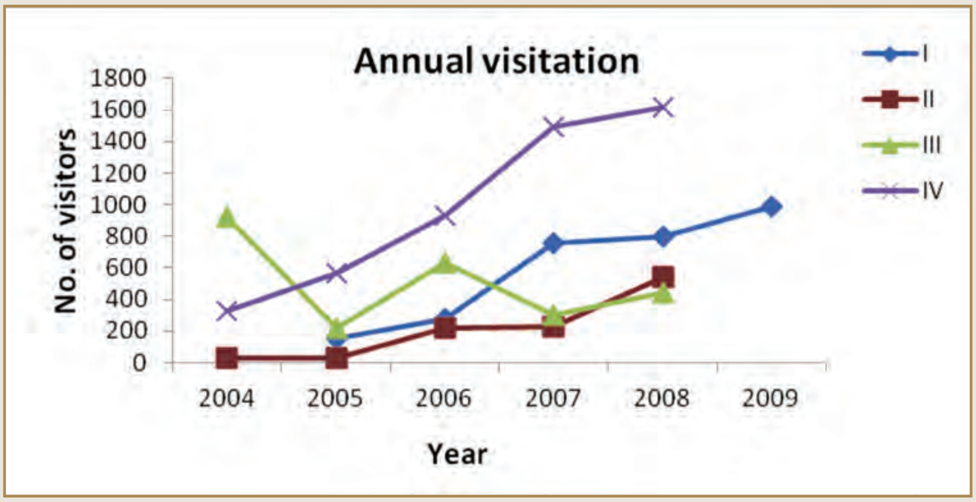
ROLE OF BUTTERFLY GARDENS AS ECOTOURISM VENTURES

Butterfly exhibition and butterfly farming have already gained the status of a booming business in many countries such as Australia, Singapore, Malaysia, Papua New Guinea, the UK and Canada (Pyle, 1995). According to an estimate made in 1987, Britain has 50 to 60 butterfly houses, attracting 5 million visitors annually, with the gate collections exceeding 5 million pounds (Collins, 1987). In North America, more than a dozen major exhibits are already operating, and many units are under construction. Similarly, the Niagara Parks Commission's Butterfly Garden in Ontario, which is a 15 million dollar facility, attracts about 20,000 visitors during weekends (Mathew, 2006). India, with its rich butterfly fauna, has great potential for alternative income production as well as rural employment opportunities by incorporating butterfly exhibition in ecotourism enterprises. Already, several villages in the north-eastern states have gone ahead with the production of butterfly curios as a cottage industry. Khoshoo (1984) has suggested that there is good scope for such enterprises in biodiversity-rich areas such as the north-eastern states, the Himalaya and the Western Ghats.

TRENDS IN VISITATION BY THE PUBLIC

During the period from April 2004 to March 2009, altogether 11,483 visitors visited the park. This number, however, does not include the number of visitors at the facility during the Open House, which was several thousands. The visitor turnout during specific periods/quarters is presented for convenience of interpretation. During the first quarter, comprising the months from January to March, an upward trend in visitation rates was observed in successive years. A total of 2973 persons visited the garden, and the average of all the years for this period was 594.7. The second quarter (April to June) had the lowest visitation rates (total, 1048; average, 209.6). The next quarter (July to September) showed a fluctuating trend, which were attributed to unpredictable rains during this period. The total number of visitors during this quarter in the 5 year period was 2519, and the average was 503.8. Similarly, the last quarter of the year (October to December) showed the highest visitor turnout, with a total of 4943 and an average of 988.6. This quarter showed a remarkable increase in visitors during the 5 year study period (Fig. 7).

Figure 7.



Quarter-wise annual visitation to KFRI Butterfly Garden (2004–2009)

CONCLUSIONS

Because of habitat enrichment and the introduction of suitable host plants, there was a marked increase in the number of butterflies visiting the garden, in terms of both individuals and species. *Pachliopta hector, Papilio polymnestor* (Papilionidae); *Catopsilia pomona, Catopsilia pyranthe* (Pieridae); *Moduza procris* (Nymphalidae); *Elymnias caudata* (Satyridae); *Talicada nyseus, Rathinda amor* (Lycaenidae); and *Danaus genutia, Danaus chrysippus, Tirumala septentrionis, Tirumala limniace, Parantica aglea* and *Euploea core* (Danaidae) were some of the species that showed a population increase in the garden. Even more interesting was the appearance of certain rare species such as *Papilio crino* (Papilionidae); *Appias* sp. (Pieridae); *Junonia orithya* (Nymphalidae); *Spalgis epius, Badamia exclamationalis* and *Potanthus* sp. (Hesperiidae), which were observed visiting the garden. Several species of butterfly have also started to colonise the area, setting up local populations.

The positive impact of the nature experiences at the KFRI butterfly garden has resulted in the setting up of butterfly gardens by various individuals, schools, colleges and business concerns. The fact that almost 90% of the visitors were school and college students highlights the immense potential of this programme in reaching out to the future citizens of the country. Setting up thematic museums and interactive exhibits will help increase the appeal of the facility to the student population. Some of the facilities established as a result of the success of this venture include the Butterfly Safari at Thenmala, which is Asia's largest butterfly park, and the butterfly garden set up in the Bioresources Nature Park at Nilambur. Butterfly parks are also being set up at Pathiramanal (Tourism Department project) and at the Indian Oil Corporation outlet at Koratty, Kerala. The results obtained in this study indicate the effectiveness of butterfly gardens in biodiversity conservation and in promoting ecotourism.

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APPENDIX I

Data on plants initially present in the study area and those subsequently introduced.

Plant species	No. of plants at the beginning of the study	No. of saplings introduced
Acestatia sp. *	-	8
Aegle marmelos+	-	9
Albizia lebbeck+	-	525
Albizia odoratissima +*	3	5
Allamanda cathartica	-	5
Angelonia biflora	-	2
Aristolochia indica +	24	75
Aristolochia grandiflora +	-	5
Bauhinia racemosa	-	1
Begonia spp *	-	30
Bombax sp. +	-	5
Bryophyllum bipinnata +	-	57
Caesalpinia pulcherima *	-	20
Calliandra inequalifolia	-	1
Calotropis gigantean +	-	6
Cananga odorata	-	3
Carissa carandus +*	-	17
Cassia biflora +*	25	7
Cassia fistula +*	2	13
Cassia occidentalis +*	-	34
Cassia tora +*	-	23
Cassia sp.	-	8
Catheranthus roseus	-	2
Centranthera sp.	-	2
Chrysanthemum morifolium *	-	25
Citrus aurantia +	-	10
Citrus aurantifolia +	-	12
Citrus limon +	14	37
Citrus medica +	-	8
Clerodendrum paniculatum *	75	250
*Clitoria ternatea**	-	4
Copsia fruiticosa	-	1
Cosmos bipinnatus	-	2
Crotalaria pallida	-	5
Crotalaria retusa	-	25
Cuphea hyssopifolia *	-	25

Cuphea miniata *	-	300
Cycas circinalis +	-	2
Doxantha unguis-cati *	-	8
Durauta plumerii	-	1
Euphorbia sp.	-	2
Ficus racemosa +	2	3
Ficus religiosa +	-	16
Evolvulus sp.	-	2
Gardenia sp. *	-	10
Gloriosa superba	-	4
Gomphrena globosa *	-	150
Heliotropium keralense	-	5
Hemidesmus indicus +	38	55
Hibiscus rosa-sinensis *	-	12
Holostemma annulare +	-	15
Hydnocarpus pentandra	-	2
Impatiens sp.	-	1
Ixora chinensis *	2	8
Ixora coccinea *	1	35
Ixora parviflora *	5	120
Ixora macrothyrsa +*	3	34
Jasminum grandiflorum	-	5
Jasminum pubescens *	-	3
Jatropa podagirica *	1	2
Kalanchoe pinnata +*	-	5
Kalanchoe suarezensis +*	-	5
Lantana camara *	25	35
Lantana sellowiana *	-	4
Michelia champaka	-	2
Mirabilis jalapa	-	2
Murraya exotica +	-	18
Murrya koenigii +	9	15
Mussaenda erythrophylla *	-	2
Mussaenda incana	-	2
Mussaenda laxa +*	-	14
Mussaenda luteola *	-	2
Nyctanthus arbor-tristis	-	
Ocimum gratissimum	-	2
Ocimum tenuifolium	-	2
Passiflora edulis +	-	8
Pentas lanceolata *	-	5
Plumeria alba	-	5
Plumeria rubra *	-	10
Pseudocalyma atata	-	2
Pyrostegia venusta	-	2

Rosa sp.	-	2
Ruellia affinis	-	2
Ruta graveolens +	-	5
Salvia splendens *	-	10
Spilanthes sp.		
Stachytarpheta mutabilis *	-	15
Strobilanthus lawsonii	-	1
Tabernaemontana coronaria	-	2
Tacca sp.	-	2
Tagetus erecta	-	5
Thottea barberi +	-	3
Thottea siliquosa +	-	3
Thunbergia erecta *	-	20
Thunbergia grandiflora	-	5
Tithonia diversifolia *	-	3
*Turnera ulmifolia**	-	4
Tylophora indica +	3	27
Vinca rosea *	-	15
Wattakaka sp. +	-	24
Wattakaka volubilis +	-	28
Zanthoxylum rhetsa +	20	15
Zinnia haageana *	-	20

** Nectar plants.*
+ Larval host plants.
- nil.

APPENDIX II

Butterflies sighted in the area during the period of study (June 1998 to November 2000)

Butterfly family/species		No. of sightings		
		First half	Second half	Total
	Papilionidae			
1	*Chilasa clytia*	81	15	96
2	*Graphium agamemnon*	5	5	10
3	*G. antiphates*	19	13	32
4	*G. sarpedon*	7	5	12
5	*Pachliopta aristolochiae*	191	175	366
6	*P. hector*	24	45	69
7	*P. pandiyana*	50	57	107
8	*Papilio buddha*	39	17	56
9	*P. crino*	0	2	2
10	*P. demoleus*	2	14	16
11	*P. helenus*	43	52	95
12	*P. liomedon*	1	2	3

13	*Papilio paris*	4	1	5
14	*P. polymnestor*	141	69	210
15	*P. polytes*	217	139	356
16	*Troides minos*	226	159	385
	Pieridae			
17	*Appias sp.*	1	7	8
18	*Catopsilia sp.*	154	93	247
19	*Delias eucharis*	24	10	34
20	*Eurema sp.*	399	288	687
21	*Leptosia nina*	1	3	4
	Acraeidae			
22	*Acraea violae*	0	32	32
	Satyridae			
23	*Melanitis leda*	17	0	17
24	*Orsotriaena medus*	1	0	1
25	*Ypthima huebneri*	1	4	5
	Nymphalidae			
26	*Cupha erymanthis*	5	3	8
27	*Ariadne merione*	0	3	3
28	*Junonia atlites*	25	36	61
29	*J. hierta*	0	3	3
30	*J. iphita*	36	38	74
31	*J. lemonias*	1	112	113
32	*J. orithya*	0	1	1
33	*Hypolimnas bolina*	0	21	21
34	*H. misippus*	1	11	12
35	*Moduza procris*	0	2	2
36	*Neptis hylas*	14	6	20
37	*Phalanta phalantha*	0	2	2
	Lycaenidae			
38	*Arhopala pseudocentaurus*	1	0	1
39	*Castalius rosimon*	5	0	5
40	*Jamides sp.*	202	315	517
41	*Rathinda amor*	0	6	6
42	*Spalgis epius*	0	3	3
43	*Talicada nyseus*	0	129	129
	Hesperiidae			
44	*Badamia exclamationis*	0	3	3
45	*Celaenorrhinus leucocera*	2	0	2
46	*Tagiades litigiosa*	1	4	5
47	*Pelopidas mathias*	2	1	3
48	*Potanthus sp.*	0	3	3
49	*Taractrocera sp.*	3	0	3
50	*Udaspes folus*	1	1	2

	Danaidae			
51	*Danaus genutia*	484	453	937
52	*D. chrysippus*	13	48	61
53	*Euploea core*	789	1186	1975
54	*Parantica aglea*	224	424	648
55	*Tirumala limniace*	359	382	741
56	*T. septentrionis*	693	1590	2283
	Grand total	4509	5993	10,502

STUDIES OF TIGER BEETLES. CCII. INDIAN TIGER BEETLE CONSERVATION (COLEOPTERA: CICINDELIDAE)

Fabio Cassola

Via F. Tomassucci 12/20, Roma 00144, Italy
email: FabioCassola@alice.it

Tiger beetles (Coleoptera: Cicindelidae) are a well-known predatory beetle family (Cassola 1999; Pearson & Vogler 2001), close to the carabids but not identical with them (Cassola 2001; Cassola & Putchkov 2005), which were recognized as a terrestrial element for assessing biodiversity richness patterns and conservation planning (Cassola & Pearson 2000) but which would reportedly be a well-studied group. Tiger beetles are especially interesting to the conservationist, because they are very good indicator elements of any habitat change and environmental degradation, as well to the biogeographer, because, despite their speedy flight, they are usually not strong fliers and remain faithful to their originary habitat, rarely wandering around more than a few dozen metres.

India is a huge country. From the northern Himalaya to the southern tip, it is almost 3000 km long, with a great variety of habitats and environments. As a consequence, its tiger beetle fauna is one of the richest of the world. My last count led to a grand total of 225 species, of which no less than 118 (*i.e*. 52.44%) are endemic to the country (Table I). Species belonging to the genus Threats were first assessed by me (Cassola 1983) and were subsequently deeply revised by Wiesner (1988), while those belonging to the genus *Pronyssa* were reviewed by Sawada and Wiesner (1999b). As to the species of the old genus *Cicindela* L. (s. auct.), they were duly reviewed by Acciavatti and Pearson (1989), and the taxonomically difficult tree-dwelling genera *Protocollyris, Collyris, Neocollyris, Tricondyla* and *Derocrania* were all reviewed by Naviaux (1995, 2002, 2003, 2004). The main reference for identifying Indian tiger beetles, however, has for many years been Fowler (1912). Additional data were provided by Heynes-Hood and Dover (1928). A few more sparse data were added by Reymond (1955), Franzen (2001), Mandl (1981, 1982), Wiesner (1975, 1992, 2008), Gebert (1992), Werner and Wiesner (1996), Sawada and Wiesner (1997, 1999a, 2006), Naviaux and Moravec (2001), Uniyal and Bhargav (2007) and Bhardwaj *et al.* (2008). Moreover, an overall evaluation of Indian tiger beetle ecological history was made by Pearson and Ghorpade (1989). I myself had also to deal several times with the fauna of the Indian subcontinent and happened to describe some species new to science (Acciavatti & Cassola 1989; Cassola 1976, 1980, 1983, 2009, 2010; Cassola & Werner 2003; Cassola & Wiesner 2009). I even personally visited south India (Karnataka, Tamil Nadu, Kerala) for collecting purposes.

This rich tiger beetle fauna, however. is presently more or less endangered. One species may already be extinct in the wild, i.e. the enigmatic nocturnal *Apteroessa grossa*, described long ago by Fabricius (1781) from the Coromandel coast (Tranquebar), present-day Tamil Nadu state. A second locality (Mayanayakanur, Ammayanayakanur Madura) is also known in the entomological literature (Wiesner 1992). The species was isolated, in modern taxonomy, because of its aberrant characters, in a special subtribe of its own (Apteroessina) (Rivalier 1971). My late friend and colleague Karl Werner, who visited India and the type locality several times, tried repeatedly, but unsuccessfully, to collect it. He related (pers. comm.) that the environment is probably much changed, that the area is presently overcrowded and that he feared that the species could well have disappeared in the wild. What would be even worse in such a case is that it wouldn't be possible in the future to better assess the taxonomical place of this species because the type series, which I saw in Paris (MNHN), unfortunately lacks a complete male specimen (Naviaux, pers. comm.).

Red Lists of threatened insect species can be politically impressive in demonstrating concern and individually valuable to the species in helping raise awareness of their plight but may do little to increase their security. Nevertheless, Red Lists of endangered insect species have been published both in the United States (where even a special Endangered Species Act, ESA was passed (New 2012b)) and are being published in many European countries (Spitzer 2012). As always, however (Bhattarai & Hammig 2004; Brown 1991; New 2012a, b, c; Pearson & Cassola 1992, 2007, 2012; Samways 1994, 2007; Samways et al. 2012), insect conservation is mainly assured by the strict and adequate protection of as many good habitats as possible (biotopes, biomes, refugia, forests, vegetation patches, savannahs, water courses). India has at present a rather good network of national parks and nature reserves. The primary goal of these protected areas is often the preservation of a "flag" or "umbrella" species, usually a mammal, such as the tiger, the tahr or some primate, whose conservation assures by itself the in situ conservation of many other species as well, including many insects. No insect lives in isolation but in a community that may include hundreds to thousands of co-occurring species. We already know that there are a lot of insect species, mainly in tropical or subtropical areas, and it is not important to know how many.

As a matter of fact, habitat loss is the first cause of insect decline. Other causes are degradation of the environment (pesticides, garbage, agricultural uses), introduction of alien species and anthropogenic climatic changes. If India has to preserve its rich endemic fauna, it is vital to stop somehow the continual growth of its human population (Eldredge 1998) in order to reduce the human environmental pressure and the potential conflicts between agriculture and wildlife. Otherwise most species, sooner or later, are sadly doomed to face extinction.

Table I. List of Indian tiger beetles (Coleoptera, Cicindelidae)

Serial number and species	Reference
COLLYRIDINAE (COLLYRIDINI, COLLYRIDINA)	
1. *Protocollyris brevilabris* (W. HORN, 1893)	Naviaux 1995
2. *Protocollyris nilgiriensis* NAVIAUX, 2003 (*)	Naviaux 2003
3. *Protocollyris pacholatkoi* NAVIAUX, 2003 (*)	Naviaux 2003
4. *Protocollyris fragilis* (NAVIAUX, 2004) (*)	Naviaux 2004
5. *Neocollyris* (*Neocollyris*) *redtenbacheri* (W. HORN, 1894)	Wiesner 1992
6. *Neocollyris (Neocollyris) schaumi* (W. HORN, 1892) (*)	Naviaux 1995
7. *Neocollyris (Neocollyris) bonellii* (GUERIN, 1834)	Wiesner 1992
8. *Neocollyris (Neocollyris) distincta* (CHAUDOIR, 1860) (*)	Naviaux 1995
9. *Neocollyris (Neocollyris) nepalensis* NAVIAUX, 1994	Sawada & Wiesner 1997
10. *Neocollyris (Neocollyris) hiekei* NAVIAUX, 1994 (*)	Naviaux 1995
11. *Neocollyris (Neocollyris) cruentata* (SCHMIDT-GOEBEL, 1846)	Naviaux 1995
12. *Neocollyris (Neocollyris) orichalcina* (W. HORN, 1896)	Naviaux 1995
13. Neocollyris *(Neocollyris) intermedia* (Naviaux 1994)	Naviaux 2004
14. *Neocollyris (Neocollyris) egregia* NAVIAUX 2004 (*)	Naviaux 2004
15. *Neocollyris (Neocollyris) fuscitarsis* (SCHMIDT-GOEBEL, 1846)	Naviaux 1995
16. *Neocollyris (Neocollyris) insignis* (CHAUDOIR, 1864) (*)	Naviaux 1995
17. *Neocollyris (Neocollyris) smaragdina* (W. HORN, 1894) (*)	Naviaux 1995
18. *Neocollyris (Neocollyris) saphyrina* (CHAUDOIR, 1850)	Naviaux 1995
19. *Neocollyris (Brachycollyris) purpureomaculata* (W. Horn, 1922)	Sawada & Wiesner 1999a
20. *Neocollyris (Isocollyris) roeschkei* (W. HORN, 1892) (*)	Naviaux 1995
21. *Neocollyris (Isocollyris) pearsoni* NAVIAUX, 1994 (*)	Naviaux 1995
22. *Neocollyris (Isocollyris) ingridae* NAVIAUX, 2004 (*)	Naviaux 2004
23. *Neocollyris (Isocollyris) annulicornis* NAVIAUX, 2004 (*)	Naviaux 2004
24. *Neocollyris (Isocollyris) macilenta* NAVIAUX, 2004 (*)	Naviaux 2004
25. *Neocollyris (Paracollyris) cyaneipalpis (W. HORN, 1923) (*)*	Naviaux 1995
26. *Neocollyris (Paracollyris) quadrisulcata* (W. HORN, 1935) (*)	Naviaux 1995

27. *Neocollyris (Orthocollyris) crassicornis* (DEJEAN, 1825)	Naviaux 1995
28. *Neocollyris (Orthocollyris) subclavata* (CHAUDOIR, 1860) (*)	Naviaux 1995
29. *Neocollyris (Orthocollyris) attenuata* (REDTENBACHER, 1848) (*)	Naviaux 1995
30. *Neocollyris (Orthocollyris) multipilosa* NAVIAUX, 2003 (*)	Naviaux 2003
31. *Neocollyris (Leptocollyris) brancuccii* NAVIAUX, 1992 (*)	Naviaux 1995
32. *Neocollyris (Leptocollyris) brendelli* NAVIAUX, 1995 (*)	Naviaux 1995
33. *Neocollyris (Leptocollyris) parvula* (CHAUDOIR, 1848) (*)	Naviaux 1995
34. *Neocollyris (Leptocollyris) maindroni* (W. HORN, 1905) (*)	Naviaux 1995
35. *Neocollyris (Leptocollyris) variicornis* (CHAUDOIR, 1864)	Naviaux 1995
36. *Neocollyris (Leptocollyris) kollari* (W. HORN, 1901)	Naviaux 1995
37. *Neocollyris (Leptocollyris) variitarsis* (CHAUDOIR, 1860)	Naviaux 1995
38. *Neocollyris (Lordocollyris) ampullicollis* (W. HORN, 1913) (*)	Naviaux 1995
39. *Neocollyris (Mesocollyris) juengeri* NAVIAUX, 1992 (*)	Naviaux 1995
40. *Neocollyris (Mesocollyris) plicicollis* (W. HORN, 1901) (*)	Naviaux 1995
41. *Neocollyris (Mesocollyris) subtileflavescens* (W. HORN, 1913) (*)	Naviaux 1995
42. *Neocollyris (Mesocollyris) rugata* NAVIAUX, 1995 (*)	Naviaux 1995
43. *Neocollyris (Mesocollyris) conspicua* NAVIAUX, 1995 (*)	Naviaux 1995
44. *Neocollyris (Mesocollyris) fowleri* NAVIAUX, 1995 (*)	Naviaux 1995
45. *Neocollyris (Mesocollyris) metallica* NAVIAUX, 2004 (*)	Naviaux 2004
46. *Neocollyris (Stenocollyris) vannideki* NAVIAUX, 1992 (*)	Naviaux 1995
47. *Neocollyris (Stenocollyris) flava* NAVIAUX, 1995 (*)	Naviaux 1995
48. *Neocollyris (Stenocollyris) andrewesi* (W. HORN, 1894) (*)	Naviaux 1995
49. *Neocollyris (Stenocollyris) nilgirica* FOWLER, 1912 (*)	Naviaux 1995
50. *Neocollyris (Stenocollyris) anthracina* NAVIAUX, 1995 (*)	Naviaux 1995
51. *Neocollyris (Stenocollyris) rubens* (BATES, 1875) (*)	Naviaux 1995
52. *Neocollyris (Stenocollyris) compressicollis* (W. HORN, 1909)	Naviaux 1995
53. *Neocollyris (Pachycollyris) apteroides* (W. HORN, 1901) (*)	Naviaux 1995
54. *Neocollyris (Pachycollyris) foveifrons* (W. HORN, 1901) (*)	Naviaux 1995
55. *Neocollyris (Pachycollyris) assamensis* NAVIAUX, 1995 (*)	Naviaux 1995
56. *Neocollyris (Pachycollyris) coapteroides* (W. HORN, 1935) (*)	Naviaux 1995
57. *Neocollyris (Pachycollyris) smithii* (CHAUDOIR, 1864)	Naviaux 1995
58. *Collyris longicollis* (FABRICIUS, 1801)	Naviaux 1995
59. *Collyris dohrni CHAUDOIR ssp. indica* NAVIAUX, 1995	Naviaux 1995
60. *Collyris brevipennis* W. HORN, 1901 (*)	Naviaux 1995
61. *Collyris subtilesculpta* W. HORN, 1901 (*)	Naviaux,1995
62. *Collyris dormeri* W. HORN, 1898	Naviaux 1995
COLLYRIDINAE (COLLYRIDINI, TRICONDYLINA)	
63. *Tricondyla (Indotricondyla) femorata* WALKER, 1858	Naviaux 2002
64. *Tricondyla (Indotricondyla) gounellei* W. HORN, 1900 (*)	Naviaux 2002
65. *Tricondyla (Tricondyla) m.macrodera* CHAUDOIR, 1860	Naviaux 2002
66. *Tricondyla (Tricondyla) tuberculata* CHAUDOIR, 1860	Naviaux 2002
67. *Tricondyla (Tricondyla) mellyi* CHAUDOIR, 1850	Naviaux 2002
68. *Derocrania (Neoderocrania) nietneri* (MOTSCHULSKY, 1859)	Naviaux 2002
69. *Derocrania (Neoderocrania) longesulcata* (W. HORN, 1900) (*)	Naviaux 2002

70. *Derocrania (Neoderocrania) honorei* FLEUTIAUX, 1893 (*)	Naviaux 2002
71. *Derocrania (Neoderocrania) dembickyi* NAVIAUX & MORAVEC, 2001 (*)	Naviaux & Moravec 2001
72. *Derocrania (Neoderocrania) brevicollis* (W. HORN, 1905) (*)	Naviaux 2002
CICINDELINAE (MEGACEPHALINI, MEGACEPHALINA)	
73. *Grammognata euphratica* (DEJEAN, 1831)	Reymond 1955; Franzen 2001
CICINDELINAE (CICINDELINI, PROTHYMINA)	
74. *Prothyma (Prothyma) proxima* CHAUDOIR, 1860	Rivalier 1964
75. *Prothyma (Genoprothyma) assamensis* RIVALIER, 1964	Rivalier 1964
76. *Prothyma (?) hennigi* W. HORN, 1898	Wiesner 1992
77. *Heptodonta pulchella* (HOPE, 1831)	Wiesner 1992
78. *Pronyssa nodicollis* BATES, 1874	Wiesner 1992
79. *Pronyssa kraatzi* (W. HORN, 1899) (*)	Wiesner 1992; Sawada & Wiesner 1999b
80. *Pronyssa assamensis* SAWADA & WIESNER, 1999 (*)	Sawada & Wiesner 1999b
81. *Pronyssa montanea* SAWADA & WIESNER, 1999 (*)	Sawada & Wiesner 1999b
82. *Rhytidophaena limbata* (WIEDEMANN, 1823)	WIesner 1992
CICINDELINAE (CICINDELINI, THERATINA)	
83. *Therates waagenorum* W. HORN, 1900	Wiesner 1992
84. *Therates chenelli* BATES, 1878	Wiesner1992
85. *Therates annandalei* W. HORN, 1908 (*)	Wiesner 1992
86. *Therates dohertyi* W. HORN, 1905 (*)	Wiesner 1992
87. *Therates hennigi* W. HORN, 1898 (*)	Wiesner 1992
88. *Therates westbengalensis* WERNER & WIESNER 1996 (*)	Werner & Wiesner 1996
89. *Therates jendeki* SAWADA & WIESNER 1997 (*)	Sawada & Wiesner 1997
90. *Therates sausai* SAWADA & WIESNER, 1997 (*)	Sawada & Wiesner 1997
CICINDELINAE (CICINDELINI, CICINDELINA)	
91. *Cicindela (Cicindela) granulata* GEBLER ssp. *stoliczkana* BATES, 1878	Acciavatti & Pearson 1989
92. *Cicindela (Sophiodela) cyanea* FABRICIUS, 1787	Acciavatti & Pearson 1989
93. *Cicindela (Pancallia) princeps Vigors*, 1825 (*)	Acciavatti & Pearson 1989
94. *Cicindela (Pancallia) aurofasciata* DEJEAN, 1831 (*)	Acciavatti & Pearson 1989
95. *Cicindela (Pancallia) goryi CHAUDOIR*, 1852 (*)	Acciavatti & Pearson 1989
96. *Cicindela (Pancallia) angulicollis* W. HORN, 1900 (*)	Acciavatti & Pearson 1989
97. *Cicindela (Pancallia) shivah* PARRY, 1848 (*)	Acciavatti & Pearson 1989
98. *Cicindela (Ancylia) guttata* WIEDEMANN, 1823 (*)	Acciavatti & Pearson 1989
99. *Cicindela (Ancylia) andrewesi* (W. HORN, 1894) (*)	Acciavatti & Pearson 1989
100. *Cicindela (Ancylia) calligramma* SCHAUM, 1861	Acciavatti & Pearson 1989
101. *Calochroa octonotata* (WIEDEMANN, 1819)	Acciavatti & Pearson 1989
102. *Calochroa flavomaculata* (HOPE, 1831) (= *sexpunctata* Fabr. 1775 s. *auct*.)	Acciavatti & Pearson 1989
103. *Calochroa sexpunctata* (FABRICIUS, 1775) (= *aurovittata Audouin* & Brullé, 1839 s. *auct*.)	Acciavatti & Pearson 1989
104. *Calochroa whithillii* (HOPE, 1838) (*)	Acciavatti & Pearson 1989
105. *Calochroa tritoma* (SCHMIDT-GOEBEL, 1846)	Acciavatti & Pearson 1989
106. *Calochroa assamensis* (PARRY, 1844)	Acciavatti & Pearson 1989
107. *Calochroa octogramma* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989

108. *Calochroa fabriciana* (W. HORN, 1894) (*)	Acciavatti & Pearson 1989
109. *Calochroa bicolor* (FABRICIUS, 1781)	Acciavatti & Pearson 1989
110. *Calochroa hamiltoniana* (THOMSON, 1857) (*)	Acciavatti & Pearson 1989
111. *Calomera a angulata* (FABRICIUS, 1798) (= *sumatrensis* Herbst, 1806 s. auct.) Acciavatti & Pearson, 1989	
112. *Calomera fowleri* (HEYNES-WOOD & DOVER, 1928) (*)	Acciavatti & Pearson 1989
113. *Calomera* (= *Lophyridia*) *plumigera* (W. H.) ssp. *macrograptina* (ACCIAVATTI & PEARSON, 1989) (= *angulata* Fabricius, 1798 s. auct.)	Acciavatti & Pearson 1989
114. *Calomera* (= *Lophyridia*) *cardoni* (FLEUTIAUX, 1890)	Acciavatti & Pearson 1989
115. *Calomera* (= *Lophyridia*) *chloris* (HOPE, 1831)	Acciavatti & Pearson 1989
116. *Calomera* (= *Lophyridia*) *funerea* (MACLEAY)	Acciavatti & Pearson1989
117. *Calomera* (= *Lophyridia*) *quadripunctulata* (MANDL, 1969) (*)	Acciavatti & Pearson 1989
118. *Cosmodela aurulenta* (FABR.) *ssp. juxtata* (ACCIAVATTI & PEARSON, 1989)	Acciavatti & Pearson 1989
119. *Cosmodela virgula* (FLEUTIAUX, 1893)	Acciavatti & Pearson 1989
120. *Cosmodela intermedia* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989
121. *Cosmodela fleutiauxi* (W. HORN, 1893)	Acciavatti & Pearson 1989
122. *Cosmodela d. duponti* (DEJEAN, 1826)	Acciavatti & Pearson 1989
123. *Plutacia dives* (GORY, 1833) (*)	Acciavatti & Pearson 1989
124. *Plutacia notopleuralis* (ACCIAVATTI & CASSOLA, 1989) (*)	Acciavatti & Pearson 1989
125. *Lophyra (Lophya) c. catena* (FABRICIUS, 1775)	Acciavatti & Pearson 1989
126. *Lophya (Lophya) cerina* NAVIAUX & ACCIAVATTI, 1987 (*)	Acciavatti & Pearson 1989
127. *Lophya (Lophya) striatifrons* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989
128. *Lophya (Lophya) histrio* (TSCHITCHERINE, 1903)	Acciavatti & Pearson, 1989
129. *Lophya (Lophya) cancellata* (DEJEAN, 1825)	Acciavatti & Pearson 1989
130. *Lophya (Spilodia) s. striolata* (ILLIGER, 1800)	Acciavatti & Pearson 1989
131. *Lophya (Spilodia) lineifrons* (CHAUDOIR, 1865)	Acciavatti & Pearson 1989
132. *Lophya (Spilodia) parvimaculata* (FOWLER, 1912) (*)	Acciavatti & Pearson 1989
133. *Lophya (Spilodia) lefroyi* (W. HORN, 1908) (*)	Acciavatti & Pearson 1989
134. *Lophya (Spilodia) vittigera* (DEJEAN, 1825)	Acciavatti & Pearson 1989
135. *Lophya (Spilodia) multiguttata* (DEJEAN, 1825)	Acciavatti & Pearson 1989
136. *Chaetodera albina* (WIEDEMANN, 1819)	Acciavatti & Pearson 1989
137. *Chaetodera vigintiguttata* (HERBST, 1806)	Acciavatti & Pearson 1989
138. *Jansenia westermanni* (SCHAUM, 1861)	Acciavatti & Pearson 1989
139. *Jansenia pseudodromica* (W. HORN, 1932) (*)	Acciavatti & Pearson 1989
140. *Jansenia dasiodes* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
141. *Jansenia biundata* (NAVIAUX, 2010) (*)	Naviaux 2010
142. *Jansenia semisetigerosa* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
143. *Jansenia vestiplicatica* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
144. *Jansenia legnotia* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
145. *Jansenia plagatima* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
146. *Jansenia bangalorensis* CASSOLA & WERNER, 2003 (*)	Cassola & Werner 2003
147. *Jansenia ostrina* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
148. *Jansenia corrugatosa* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
149. *Jansenia cratera* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989

150. *Jansenia choriodista* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
151. *Jansenia prothymoides* (W. HORN, 1908) (*)	Acciavatti & Pearson 1989
152. *Jansenia nathanorum* CASSOLA & WERNER, 2003 (*)	Cassola & Werner 2003
153. *Jansenia crassipalpis* (W. HORN, 1908) (*)	Acciavatti & Pearson 1989
154. *Jansenia tetrastacta* (WIEDEMANN, 1823) (*)	Acciavatti & Pearson 1989
153. *Jansenia chlorida* (CHAUDOIR, 1865) (*)	Acciavatti & Pearson 1989
156. *Jansenia psarodea* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
157. *Jansenia rostrulla* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
158. *Jansenia grossula* (W. HORN, 1925) (*)	Acciavatti & Pearson 1989
159. *Jansenia venus* (W. HORN, 1907) (*)	Acciavatti & Pearson 1989
160. *Jansenia stuprata* (W. HORN, 1909) (*)	Acciavatti & Pearson 1989
161. *Jansenia fusissima* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
162. *Jansenia chloropleura* (CHAUDOIR, 1865)	Acciavatti & Pearson 1989
183. *Jansenia viridicincta* (W. HORN, 1894) (*)	Acciavatti & Pearson 1989
164. *Jansenia azureocincta* (BATES, 1878) (*)	Acciavatti & Pearson 1989
165. *Jansenia rugosiceps* (CHAUDOIR, 1865) (*)	Acciavatti & Pearson 1989
166. *Jansenia sandurica* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
167. *Jansenia motschulskyana* (W. HORN, 1893) (*)	Acciavatti & Pearson 1989
168. *Jansenia indica* (FLEUTIAUX, 1893) (*)	Acciavatti & Pearson 1989
169. *Jansenia reticulella* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
170. *Jansenia tetragrammica* (CHAUDOIR, 1865) (*)	Acciavatti & Pearson 1989
171. *Jansenia applanata* (ACCIAVATTI & PEARSON 1989) (*)	Acciavatti & Pearson 1989
172. *Cylindera (Cylindera) obliquefasciata (descendens* FISCHER, 1825)	Gebert 1992
173. *Cylindera (Cylindera) dromicoides* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989
174. *Cylindera (Cylindera) delavayi* (FAIRMAIRE, 1886)	Acciavatti & Pearson 1989
175. *Cylindera (Glomera) belloides* (W. HORN, 1907) (*)	Acciavatti & Pearson 1989
176. *Cylindera (Glomera) ochrocnemis* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
177. *Cylindera (Setinteridenta) rhytidopteroides* (W. HORN, 1924)	Acciavatti & Pearson 1989
178. *Cylindera (Oligoma) paradoxa* (W. HORN, 1892)	Acciavatti & Pearson 1989
179. *Cylindera (Oligoma) lacunosa* (PUTZEYS, 1875)	Acciavatti & Pearson 1989
180. *Cylindera (Ifasina) foveolata* (SCHAUM, 1863)	Acciavatti & Pearson 1989
181. *Cylindera (Ifasina) cyclobregma* (ACCIAVATTI & PEARSON, 1989)	Acciavatti & Pearson 1989
182. *Cylindera (Ifasina) viduata* (FABRICIUS, 1801) (= triguttata Herbst, 1806, s. *auct*.)	Acciavatti & Pearson 1989
183. *Cylindera (Ifasina) viridilabris* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989
184. *Cylindera (Ifasina) labioaenea* (W. H.) ssp. *fuscocuprascens* (W. HORN, 1905)	Acciavatti & Pearson 1989
185. *Cylindera (Ifasina) fallaciosa* (W. HORN, 1897)	Sawada & Wiesner 1997
186. *Cylindera (Ifasina) severini* (W. HORN, 1892) (*)	Acciavatti & Pearson 1989
187. *Cylindera (Ifasina) collicia* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
188. *Cylindera (Ifasina) karli* CASSOLA, 2009 (*)	Cassola 2009
189. *Cylindera (Ifasina) nietneri* (W. HORN, 1894)	Acciavatti & Pearson 1989
190. *Cylindera (Ifasina) umbropolita* (W. HORN, 1905) (*)	Acciavatti & Pearson 1989
191. *Cylindera (Ifasina) seriepunctata* (W. HORN, 1892)	Acciavatti & Pearson 1989
192. *Cylindera (Ifasina) melitops* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989

193. *Cylindera (Ifasina) s. spinolai* (GESTRO, 1889)	Acciavatti & Pearson 1989
194. *Cylindera (Ifasina) paucipilina* (ACCIAVATTI & PEARSON, 1989)	Acciavatti & Pearson 1989
195. *Cylindera (Ifasina) limitisca* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
196. *Cylindera (Ifasina) subtilesignata* (MANDL, 1970)	Acciavatti & Pearson 1989
197. *Cylindera (Ifasina) decempunctata* (DEJEAN, 1825)	Acciavatti & Pearson 1989
198. *Cylindera (Ifasina) anelia* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
199. *Cylindera (Ifasina) sikhimensis* (MANDL, 1982)	Acciavatti & Pearson 1989
200. *Cylindera (Ifasina) k. kaleea* (BATES, 1866)	Acciavatti & Pearson 1989
201. *Cylindera (Eugrapha) bigemina* (Klug, 1834)	Acciavatti & Pearson 1989
202. *Cylindera (Eugrapha) brevis* (W. Horn, 1905)	Acciavatti & Pearson 1989
203. *Cylindera (Eugrapha) procera* (W. HORN, 1905) (*)	Acciavatti & Pearson 1989
204. *Cylindera (Eugrapha) minuta* (OLIVIER, 1790)	Acciavatti & Pearson 1989
205. *Cylindera (Eugrapha) cognata* (WIEDEMANN, 1823)	Acciavatti & Pearson 1989
206. *Cylindera (Eugrapha) erudita* (WIEDEMANN, 1823)	Acciavatti & Pearson 1989
207. *Cylindera (Eugrapha) agnata* (FLEUTIAUX, 1890)	Acciavatti & Pearson 1989
208. *Cylindera (Eugrapha) ancystridia* (ACCIAVATTI & PEARSON, 1989) (*)	Acciavatti & Pearson 1989
209. *Cylindera (Eugrapha) venosa* (KOLLAR, 1836)	Acciavatti & Pearson 1989
210. *Cylindera (Eugrapha) grammophora* (Chaudoir, 1852)	Acciavatti & Pearson 1989
211. *Cylindera (Eugrapha) singalensis* (W. HORN, 1911)	Acciavatti & Pearson 1989
212. *Cylindera (Eugrapha) sublacerata* (SOLSKY, 1874)	Acciavatti & Pearson 1989
213. *Cylindera (Eriodera) albopunctata* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989
214. Myriochila (Myriochila) melancholica (FABRICIUS, 1798)	Acciavatti & Pearson 1989
215. *Myriochila (Myriochila) undulata* (DEJEAN, 1825)	Acciavatti & Pearson 1989
216. *Myriochila (Myriochila) dubia* (W. HORN, 1892)	Acciavatti & Pearson 1989
217. *Myriochila (Myriochila) atelesta* (CHAUDOIR, 1852)	Acciavatti & Pearson 1989
218. *Myriochila (Myriochila) distinguenda* (DEJEAN, 1825)	Acciavatti & Pearson 1989
219. *Myriochila (Monelica) fastidiosa* (DEJEAN, 1825)	Acciavatti & Pearson 1989
220. *Hypaetha quadrilineata* (FABRICIUS, 1781)	Acciavatti & Pearson 1989
221. *Hypaetha biramosa* (FABRICIUS, 1781)	Acciavatti & Pearson 1989
222. *Callytron limosum* (SAUNDERS, 1836)	Acciavatti & Pearson 1989
223. *Callytron gyllenhalii* (DEJEAN, 1825)	Acciavatti & Pearson 1989
224. *Callytron malabaricum* (FLEUTIAUX & MAINDRON, 1903) CICINDELINAE (CUCUINDELINI, APTEROESSINA)	Acciavatti & Pearson 1989
225. *Apteroessa grossa* (FABRICIUS, 1781) (*)	Wiesner 1992

Excluded species:

Neocollyris (OrthoCollyris) acuteapicalis (W. HORN, 1913) (Naviaux 1995: Bengal)
Neocollyris (Pachycollyris) bipartita (FLEUTIAUX, 1897) (Naviaux 1995: Assam)
Tricondyla (Tricondyla) bengalensis (NAVIAUX, 2002) (Naviaux 2002: Bangladesh)
Prothyma (Prothyma) scrobiculata (WIEDEMANN, 1823) (Wiesner 1992: Bangladesh)
Prothyma (Prothyma) bordonii CASSOLA, 1980 (Bangladesh)
Lophyridia littoralis (FABR.) *ssp. conjunctaepustulata* (DOKHTOUROFF, 1887) {Mandl 1981, 1982 (Bombay), Acciavatti & Pearson 1989}
Myriochile (Monelica) akhteri CASSOLA & WIESNER, 2009 (Pakistan)

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ASSESSMENT OF ENVIRONMENTAL STRESSES ON HIMALAYAN WETLANDS THROUGH MORPHOLOGICAL DEFORMITIES IN CHIRONOMIDAE (INSECTA: DIPTERA)

Girish Maheshwari and Geeta Maheshwari

School of Entomology, St. John's College, Agra 282 002, Uttar Pradesh, India
email: girish_maheshwari@yahoo.com

ABSTRACT

Chironomids, commonly known as midges, are mosquito-like insects whose larvae (blood worms) live in the sediments of all types of aquatic habitats. Chironomids can be an important freshwater indicator. The larvae of some species are sensitive to specific forms of pollution, whereas others are quite tolerant. Excellent water quality conditions are often characterized by relatively low densities and a high species diversity, 50% or more of the species being blood worms. Sediments contaminated with trace metals and other pollutants harbor chironomids whose chromosomal activity levels are reduced, which could reflect lowered metabolic activity and inhibited RNA synthesis—the critical process by which DNA is translated to proteins. The important role that blood worms play in the food web is also significant for the possible transfer of contaminant Himalayan wetlands are of the oligotrophic type and are situated 4000 m above msl. They include Tso Moriri, Tsokar, Startaspuk Tso , Kyagar ,Yeye Tso , Pangong Tso, Chandratal, Surajtal, Dashauhar and Brighu . These wetlands support more than 50 species of the family Chironomidae, belonging to the subfamilies Diamesinae, Orthocladinae, Tanypodinae and Chironominae. Deformities and chromosomal aberrations were observed in Diamesa, Sympotthastia, Pagastia, Pseudokiefferiella, Pseudodiamesa, Abiskomyia, Corynoneura and others. Deformities indicate sulphur deposition (as sulphates) and changes in the concentrations of magnesium, calcium, sodium and aluminium.

INTRODUCTION

Blood worms are considered to be one of the most important bioindicators of water quality and have attained importance in the concept of bio- indication. Bio-indication is a well-established idea used in various types of water analysis the world over. Ideally, reliable indicators are those taxa that have a narrow and specific tolerance (*Corynoneura* spp.), while organisms that have a wide tolerance are often less informative and poor indicators of water quality (*Micropsectra* spp.). Bio-indicators may be used to understand the response, adaptation and recovery of ecosystems and their components to natural and anthropogenic disturbances. Blood worms can provide information and early warnings at the ecosystem, population and genetic level and provide insights into potential casual mechanisms.

Our recent investigation in wetlands of the Himalaya indicate that their species richness, population compositions and temporal changes reflect the sediment quality. Deformed and non-deformed larvae most often did not differ in length and weight. The energy content and dry weights in one population were lower in normal larvae compared with weak and deformed ones.

The predictable responses of populations of certain species to varying levels of a variety of a pollutants resulted in the use of larval chironomids (blood worms) as biological indicators of water and sediment quality (Maheshwari & Maheshwari 1999) . Additionally, blood worms are essential components in the efficient biological processing that takes place in oxidation. Blood worms can serve as sources of qualitative and quantitative biological information in water quality monitoring systems. They have excellent salivary gland chromosomes, which are promising tools for assessing genotoxicity in the environment. Due to their good resolution, they allow the detection of a broad range of cytogenetic aberrations at the structural and functional levels. Somatic structural aberrations (inversions, deletions, deficiencies, amplification and others) can be used as bio-markers at the cytogenetic level for measuring the toxic effects of different stress agents in the environment. Due to deletions in chromosome G in some chironomid species, chromosome was transformed to the so-called pompon-like chromosome G, which can be used to test the genotoxicity of various agents in an aquatic ecosystem. It is emphasized that the BR (Balbiani Ring) system is a very interesting model for studying the response of the genome to pollutants in the environment. Together with the standard activity of this system, a clear reversed level of activity was observed. Changes in the activity of the nucleolar organizer were also detected. It has been shown that these important key structures are affected by trace metal toxicity. They concentrate mainly at or close to sites rich in repetitive DNA loci. Structural and functional aberrations in polytene chromosomes can serve as early-warning indicators of environmental pollution (Michailova 2010).

All the high-altitude wetlands of the Himalaya are oligotrophic and are little affected by large human populations, industrial development and effluents. The major factors that influence their integrity and hydrochemistry are biodiversity degradation, road construction, tunnelling, changes in paths of torrential streams, erosion of rocks and changes in catchment area.

Table 1. Physico-chemical characteristics of oligotrophic wetlands of the Himalaya

S. no.	Parameter	Nature of oligotrophic lake	
		Fresh water	Saline water
1	pH	6.2–9.6	6.2–9.6
2	Transparency (m)	7–10	7–10
3	D.O. (mg/L)	4.2–8.0	4.2–8.0
4	Total hardness	40–70	2000–2200
5	Conductivity (μS/cm)	42–132	42–132
6	Ammonia (mg/L)	0-0.32	0–0.32
7	Magnesium (mg/L)	19–70	400–532
8	Potassium (mg/L)	1–2.9	70–175
9	Sulphate (mg/L)	100–300	100–300
10	Silicate (mg/L)	0.2–5.3	0.2–5.3
11	Chloride (mg/L)	6–9.5	66–5250
12	Phosphate (mg/L)	0.23–0.70	0.23–0.70
13	Calcium (mg/L)	20–41	200–2000
14	Iron (mg/L)	0–0.68	2–2.8
15	Nitrate (mg/L)	20–40	20-40
16	Fluoride (mg/L)	0–0.26	0–0.26
17	Sodium (mg/L)	0–2.12	0–2.12
18	Aluminium (mg/L)	0–0.12	0–0.12
19	Manganese (mg/L)	0–03	0–07
20	Copper (mg/L)	0–0.022	0–0.022
21	Zinc (mg/L)	0–0.090	0–0.090
22	Chromium (mg/L)	5–15	5–15
23	Cadmium (mg/L)	0–0.18	0–0.18
24	Lead (mg/L)	0–0.558	0–0.558
25	Nickel (mg/L)	0–0.636	0–0.636
26	Arsenic (mg/L)	0–0.0051	0–0.0051
27	Mercury (mg/L)	0–0.0032	0–0.0032

METHODOLOGY

COLLECTION TECHNIQUE

Blood worms were collected along with mud using a Petersen dredge from various wetlands of the Ladakh Himalaya. Collection from littoral and sub-littoral zones was by scraping the mud surface with enamel pans and a Mundie sampler. The blood worms were washed from the mud samples usin the magnesium sulphate floating method. They were also collected using a brush from the snow surface.

PRESERVATION AND TRANSPORT OF MATERIAL

The collected material was preserved in Pample's fluid. The blood worms were transported in small sand bags and in hollowed potatoes. They were brought alive and healthy to the laboratory.

CULTURE OF CHIRONOMIDAE

An artificial diet was provided to the images of the chironomids in the laboratory. The artificial diet was prepared using the method of Singh and Moore (1985). Two grams of liver powder was mixed with 250 mL of warm tap water in a 1000 mL flask. The mixture was allowed to subside, and the resulting artificial larval diet was stored at 5°C. Generally, the larval diet was discarded after 2 weeks.

DISSECTION AND EXAMINATION

The blood worms were placed in 10% lactic acid for cleaning. They were examined in 70% ethanol, and important characters were noted. The larva was transferred to a glass well slide (cavity slide) containing a drop of glycerine. It was dissected under a stereoscopic zoom binocular microscope, and the head, thorax and abdomen were passed through successive baths of 2-propanol, 2-propanol layered over cedarwood oil, cedarwood oil and Canada balsam.

The respiratory organ of blood worms is rich in taxonomic characters, and therefore it needs to be prevented from collapsing. Towards this, the respiratory organ and a part of the cuticle were removed and placed in 5% glycerine and in 70% ethanol in an open 3-drop vial. The alcohol was evaporated by mild heating. The respiratory organ, with the glycerine, was mounted on a slide for study.

HEAVY AND TRACE METAL ANALYSIS

Twenty-seven heavy and trace metals were analysed using an atomic absorption spectrophotometer (Perkin), a UV–vis spectrophotometer (Perkin) and an ion selectivity meter. Polytene chromosomes were prepared using Michailova's method of 1989.

STUDY AREA

The north-west Himalaya lie between the rivers Sutlej and Indus and stretch between latitudes 31° and 36° N. Thus they are very wide. A large number of high-altitude lakes are scattered in this region. The high-altitude wetlands of Ladakh are mainly found in the Changthang region, between 4000 m and 5000 m altitude. The Changthang region (also called the Rupshu-Khanak region), meaning 'northern plains', lies in the Leh and Nyoma blocks of Leh district, in south-eastern Ladakh. It is an extention of the Tibetan Changthang. Changthang's most striking feature is the absence of a consistent slope, which would enable water to drain away. Rather, the undulating land forms huge basins into which snow-melt streams flow. Finding no outlet, the water settles into the great brackish lakes. Two massive brackish lakes, Pangong Tso and Tso Moriri, with an extent of around 700 km^2 and 140 km^2, respectively; two drainage systems (each containing twin lakes), one of which is of fresh water and drains into a low self-filled basin (Startsapuk Tso–Tsokar and Kyun Tso I–Kyun Tso II); the Hanle riverine system and flood plain marsh; and the Nuro Sumdo valley bog specifically merit listing among the most important high-altitude wetlands of Ladakh. Kyagar and Yeye Tso are also important lakes of the Ladakh Himalaya. Two oligotrophic lakes of the Pir Panjal Range, Dashauhar and Brighu were investigated for hypsobiont blood worms. Surajtal) and Chandratal at an altitude of 4400 m, are two other important fresh water lakes of Lahaul Spiti (Plate I).

RESULTS

CHARACTERIZATION OF OLIGOTROPHIC LAKES OF THE HIMALAYA

Oligotrophic lakes contain very low concentrations of the nutrients required for plant growth, and thus the overall productivity of these lakes is low. Only a small quantity of organic matter grows in an oligotrophic lake; the phytoplankton, the zooplankton, the attached algae, the macrophytes (aquatic weeds), the bacteria, and the fish are all present as small populations. There is little growth, as when corn is planted in sandy soil. There may be many species of plankton and many different types of other organisms, but there are not very many of each species or type. There may be some big fish, but there are not many of them. With so little production of organic matter, there is very little accumulation of organic sediment on the bottoms of oligotrophic lakes, and thus with little organic food, we find only small populations of bacteria. Moreover, with only small numbers of plankton and bacteria, we have very little consumption of oxygen in the deeper waters. One typical feature of an oligotrophic lake is a high availability of oxygen from the surface to the bottom. Other features include good water clarity (a deep Secchi disk reading, averaging about 10 m, or 33 feet), few suspended algae, the phytoplankton, wtih low chlorophyll readings (average about 1.7 mg/m^3) and low nutrient levels, typified by phosphorus (averaging about 8.0 mg/m^3). There are other chemical characteristics, but these are the ones mentioned most often. The bottoms of oligotrophic lakes are most often sandy and rocky, and usually their watersheds are of a similar nature. As a result, there is little inflow of nutrients into such lakes.

DEFORMITIES IN THE HEAD CAPSULE

Mouthpart deformities were observed in species of *Corynoneura, Diamesa, Syndiamesa, Pseudodiamesa* and *Abiskomyia*.

Examination of the antennae was carried out only for gross deformities, such as missing or extra segments and the presence of extra pairs or major differences in the sizes of segments between the two antennae. Epipharyngis and mandibles were classified as deformed if they exhibited extra teeth, missing teeth, including gaps, or had more than one pair of antenna and mouth parts or were very asymmetrical or abnormal in shape. Antennae or mandibles damaged as a result of the cleaning and mounting process usually have abrupt breaks that are readily visible and are easily distinguishable from deformed structures. Therefore these were not considered in the present study. Deformities of the mentum and ligula in the dominant *Pseudodiamesa* taxa at Surajtal and Dashauhar lakes included missing teeth and fused teeth and were the commonest types of deformities. An extra mentum was recorded in *Syndiamesa*. Although split teeth were observed in *Abiskomyia* species at this site, they were less common than other deformities throughout the sampling years. At Chandratal, fused teeth, Köhn gaps and missing teeth were the commonest types of deformitie. Missing teeth were the dominant type of deformity observed among *Corynoneura* taxa. Multiple deformities were observed among *Psedodiamesa* taxa at Brighu Lake of Pir Punjal Range. No mandible deformities were seen among the dominant chironomid taxa of Tso Moriri Lake. Fifteen to twenty percent of the blood worms were found to be deformed at Surajtal and Dashauhar lakes. Twenty percent of the female genitalia of *Diamesa* and *Pseudodiamesa* exhibited gynandromorphism (Maheshwari & Maheshwari 2003) (Plate I).

The standard karyological characteristics of some chironomid species can be employed as a basis to reveal environmental mutagens by studying chromosome aberrations; appearance of heterochromatin; and changes in the functional activity of the polytene chromosomes and the activity of key structures, such as Balbiani rings (BRs) and the nucleolar organizer (NOR). Heavy metals are very important in trace quantities for normal cellular functions in the blood worms of oligotrophic wetlands. Most of them form active sites in a number of enzymes involved in oxidation–reduction reactions. However, they can be toxic to cells once their levels exceed physiological values. The effect of heavy metals can manifest itself at high concentrations over short periods, causing acute toxicity, or at low concentrations over long periods of time, causing chronic toxicity, leading to disorders in vital functions, such as abnormalities in morphology, growth, maturation, reproduction and hatching (Michailova 2010). Many functional alterations were observed both in the field and in the lab, when chironomid materials were exposed to different concentrations of trace metals. The response of chironomid genomes to different stress agents in nature, as well as to trace metals in the lab, is characterized by changes in gene expression, clearly manifesting themselves in the puff activity of BRs and NOR. BRs are key structures as they are sites of intense transcription of genes encoding silk proteins (Wieslander 1994). These proteins are very important for chironomids due to their participation in the construction of the tubes where larvae develop. The nucleolar organizer function is essential for cell maintenance and ribosomal production, which is highly conserved through evolution (Planello *et al*. 2007).

DISCUSSION

There are different hypotheses about the effects of trace metals on a species and its genome. Naturally, there is chemical speciation of trace metals, and it can therefore increase their bioavailability. Kleimann *et al*. (1981) found that chironomids from an acidic lake polluted with trace metals could also regulate the accumulation of copper, zinc and, to some extent, manganese. Karlik *et al.* (1980) noted that aluminium forms different complexes, depending on the pH. At high pH values, the presence of aluminium has a stabilizing effect upon DNA as the metal binds to its phosphate groups. At low pH values, aluminium can destabilize the DNA double helix because it preferentially binds to denaturized DNA and forms cross links between strands, forming the so-called Complex II (Karlik *et al.* 1980).

Copper is known to destabilize DNA, possibly through localized production of hydroxyl radicals (Bremner 1998). Zinc generally has a beneficial effect on the genome by, for example, reducing the toxicity of cadmium (Nocentini 1987; Coogan *et al*. 1992). Excess zinc can, however, lead to an increase in reactive iron, which can damage DNA through reaction with hydrogen peroxide to produce hydroxyl radicals (Elgohary *et al.* 1998). Copper and zinc also influence gene expression by, for example, regulating the activity of detoxification–associated metallothionein genes. Sanderson *et al.* (1980), who studied the Black Fly *Simulium vitatum*, found that aluminium toxicity may be related to alterations in gene expression. However, special molecular analysis of the genome is required to confirm that such mechanisms operate in chironomid species. The screening of deformities in the blood worm reveals evidence of deteriorating water quality in the Himalayan wetlands. The method is particularly useful because it could detect sub-lethal effects of pollution at sub-organism levels and blood worms may serve as early warning indicators to water resources managers. The mentum proved most useful because it appears to have a wider range of sensitivity and is easy to prepare for examination, and deformities can be quantified rapidly. The study of chironomid deformities added value to the evidence gathered in the multi-criteria investigation of pollution in the lakes, especially sulphur deposition.

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PLATE I

Chandratal (4070 m)

Dashauhar (4200 m)

Yeye Tso (4620 m)

Brighu (4132 m)

Pangong Tso (4218 m)

Tso Moriri (4511 m)

Surajtal (4864 m)

Startsapuk Tso (4580 m)

DIVERSITY AND INDICATOR SPECIES OF MOTH (LEPIDOPTERA: HETEROCERA) ASSEMBLAGES IN DIFFERENT VEGETATION ZONES IN GANGOTRI LANDSCAPE, WESTERN HIMALAYA, INDIA

***Abesh Kumar Sanyal*[1]*, V.P. Uniyal*[1]*, Kailash Chandra*[2] *and Manish Bhardwaj*[1]**

1. Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand, India.

2. Zoological Survey of India, Prani Vigyan Bhawan, M-Block, New Alipore, Kolkata 700 053.

email: uniyalvp@wii.gov.in

ABSTRACT

In comparison with higher plants and larger animals, the inventory of insects in the western Himalaya is fragmentary and incomplete due to the taxonomic complexity and lack of expertise. This has made the monitoring and conservation of insect biodiversity an impractical thing for the protected area managers. So, instead of studying the entire insect community, attention should be given to identifying an easy-to-monitor assemblage that serves as a surrogate for the entire insect community and acts as indicator of changes in habitat quality. The order Lepidoptera, comprising butterflies and moths, is suitable for this purpose. Although butterfly taxonomy and distribution are relatively well studied, there is a large knowledge gap about the moths in the western Himalaya. In this study, attempts were made to investigate the moth species composition in different vegetation zones within the Gangotri Landscape Area and to compare sites in terms of their family and species compositions. In addition, a preliminary attempt was made to identify different indicator species of moth for these different zones. With 20 sampling sites, six major vegetation zones were identified: Pine Forest, Agricultural Mixed Land, Mixed Riverine Forest, Broadleaved Forest, Conifer Forest and Alpine Scrubland. Sixteen families and 1992 specimens of moths were recorded from these 20 sites and were primarily sorted into 784 morphospecies. The family Geometridae was the most dominant family in all the zones, with 522 individuals and 186 species. The species richness was found to be highest in the Mixed Riverine Forest, while the lowest was found to be in the alpine scrubland. Mixed Riverine and Conifer forests were characterized by six species and four species of moth respectively, with high indicator scores, while other, less homogenous zones showed generally species with low mean indicator values. We assume that monitoring the abundance dynamics of this indicator assemblage of moth species will help understand the future changes in quality and composition of the vegetation zones concerned.

INTRODUCTION

Invertebrates are the most diverse and abundant animals in most natural ecosystems, but their significance in sustaining these ecosystems is commonly not appreciated (New 1995). Determining the distribution of invertebrates is an integral part of assessing their conservation status and determining their possible management needs. Invertebrates, and in particular insects, can therefore not be ignored in the assessment of biodiversity (Holloway *et al.* 1991). The reluctance to use invertebrates in conservation studies, as indicated by Cardoso *et al.* (2011), is mainly because of the following reasons: (1) Invertebrates and their ecological services are mostly unknown to the general public. (2) Policy makers and stakeholders are mostly unaware of invertebrate conservation problems. (3) Basic scientific work on invertebrates is scarce and under funded. (4) Most species have not been described. (5) The distribution of described species is mostly unknown. (6) The abundances of species and their changes in space and time are unknown. (7) Species' ways of life and sensitivities to habitat change are largely unknown. Furthermore, invertebrate surveys generate very large samples that demand considerable effort to process in terms of time and expertise (New 1999a). Despite the above negative aspects of working with invertebrates, they represent a group of organisms that are potentially useful when assessing the biodiversity of an area because of (1) their generality of distribution, (2) trophic versatility, (3) rapid responses to perturbations and (4) ease of sampling (Holloway *et al* 1991). There are so many taxa for which the expertise to identify to the level of species does not exist that we cannot even contemplate surveying their diversity entirely. At the current rate, it will take us several thousand years to describe all the species or have an idea about the diversity if traditional taxonomic methods are used (McNeely *et al.* 1995).

The Himalaya, as part of the world's largest mountain ecosystem, harbours a diverse and unique assemblage of biodiversity due to its position in the tri-junction of the Oriental, Palaearctic and Ethiopian realms. An inventory of biodiversity is of primary importance as part of biodiversity conservation for sustainable development, particularly in threatened and fragmented landscapes such as the Western Himalaya, which harbour a unique assemblage of flora and fauna of considerable conservation importance. In comparison with higher animals, the inventory of insects in the Western Himalayan landscape is still fragmentary and incomplete due to the taxonomic complexity and lack of expertise for species-level identification. This has made the monitoring and conservation of insect biodiversity an impractical thing for protected areas managers.

So, it is of utmost importance that instead of studying the entire insect community, attention be given to identifying and selecting an easy-to-monitor assemblage that serves as a surrogate for the entire insect community and acts as an indicator of changes in habitat quality. The order Lepidoptera, comprising butterflies and moths can easily serve this purpose as these insects are taxonomically well known and critical to the functioning of many ecosystems, with the species having functional roles as selective herbivores, pollinators and prey for birds and small mammals (Schowalter *et al*. 1986, Perry 1994). In recent years, in North America and Europe attempts have been made to establish the lepidopteran assemblage as indicators in ecological studies assessing the impact of fragmentation (Summerville & Crist 2001), selective logging (Dumbrell & Hill 2005), grazing (Poyry *et al*. 2005), fire (Fleishman 2000), exotic and invasive plants (Fleishman *et al*. 2005), *etc.*

The Lepidoptera have been proposed as surrogate species by several authors (Kremen 1992, Beccaloni & Gaston 1995, Fleishman *et al*. 2000). Several features of the butterflies and moths make them good candidates for indicator, umbrella and/or flagship species (New 1997, Fleishman *et al.* 2000, Maes & Van Dyck 2001). They have a wide distribution and are relatively easy to sample and identify, and both as individuals and as species they are present in significant numbers in different ecosystems (Blair 1999, Caro & O'Doherty 1999, Ricketts *et al*. 2002). They are also strongly influenced by the local weather and are highly sensitive to environmental changes (Spitzer *et al*. 1997), besides being charismatic insects that could attract the public attention. Finally, some authors have identified patterns of co-variation between the abundance and/or the richness of the Lepidoptera and members of other taxonomic groups (Blair 1999, Swengel & Swengel 1999). However, these relationships are highly dependent on the taxa and the spatial scales considered (Ricketts *et al*. 2002). Butterflies and moths are extremely sensitive to changes in vegetation composition and structure, and different types of vegetation show different species compositions. So, butterfly and moth assemblages may be used to characterize different habitats (Erhardt 1985). Plants are the essential source of nourishment of butterflies and moths: some specific plant species provide the trophic resources for caterpillars, while others provide nectar for adults. The vegetation can also play an important role for their survival, offering particular structural elements for sun-basking or mating and determining certain suitable microclimates (Dover *et al*. 1997). Therefore, it would be expected that butterflies and moths will respond more strongly to vegetation gradients than to edaphic gradients (Sawchik *et al.* 2003).

Although butterfly taxonomy and distribution have been relatively well studied in the Indian Western Himalayan perspective, moth study lacks significant additions, except Smetacek (2008), since the work of Hampson (1892, 1894, 1895, 1896) and Bell and Scott (1937) in their Fauna of British India series and Cotes and Swinhoe's (1886) "A catalogue of Moths of India". Butterflies are also not easily trapped (Kitching *et al*. 2000) and are often poorly represented in forest environments as they prefer open, sunny habitats. Although they have been advocated as indicator taxa in grasslands and tropical forests, they account for only about 15% of the lepidopteran species diversity worldwide (Summerville & Crist 2004). In contrast, the nocturnal families of larger Lepidoptera are sufficiently speciose and diverse to offer powerful discrimination in detecting ecosystem level impacts (Holloway 1977, 1985). Most families of moth are readily attracted to light traps, which, used with care, can provide a standard measure of the fauna present in a particular habitat.

Keeping in mind all these lacunae and the potential of the moth assemblage, the current study aimed to provide a complete inventory of the moth species assemblage along altitudinal gradients in the different vegetation zones available in the Gangotri Landscape Area. Just as every pristine and ecologically important habitat is facing the threat of degradation and loss of area due to anthropogenic disturbances, so too is this true with the Western Himalaya. Although the principal threat is loss, degradation and fragmentation of natural habitats in Western Himalayan protected areas overall, the Indian situation is a little optimistic. The forest cover remains extensive and relatively stable in most of the north-western Indian states although destruction of the understorey forest due to extensive overgrazing and loss or conversion of forest lands due to developmental activities such as construction of roads and dams and expansion of agriculture are causing major damage. These problems are also evident in the Gangotri Landscape, which comprises three important high altitude protected areas in the Indian state of Uttarakhand: Govind Wildlife Sanctuary, Govind National Park and Gangotri National Park. The extensive coniferous, broadleaf and mixed forests and montane grassland patches, with adjacent subalpine forests, of this landscape may be the last resort for many endangered and vulnerable species of animal.

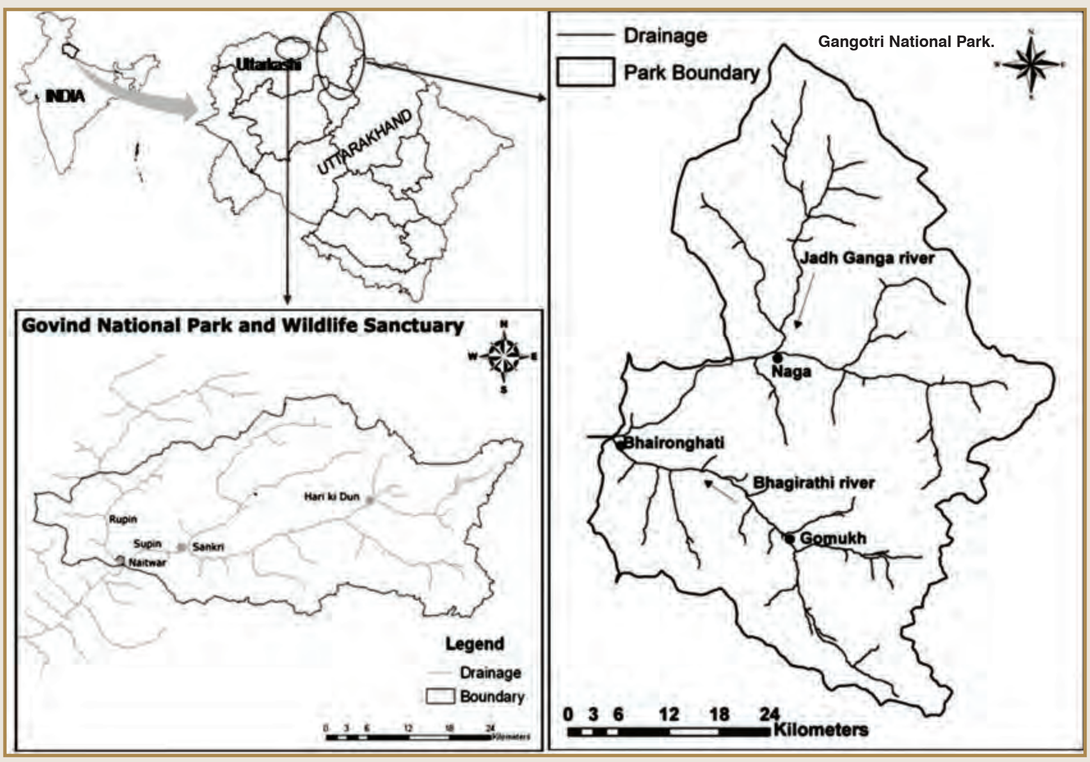
The objectives of the study were to investigate the moth species composition in different vegetation zones within the Gangotri Landscape Area and to compare sites in terms of their family and species compositions. In addition, a preliminary attempt was made to identify different indicator species of moth for different vegetation zones and in different disturbance regimes.

MATERIALS AND METHODS

STUDY AREA

The study was conducted in three high altitude protected areas of, district Uttarkashi, Uttarakhand (Fig. 1): Gangotri National Park (NP) (latitude 30°50’-31°12’ N and longitude 78°45’-79°02’ E) and Govind National Park and Govind Wildlife Sanctuary (latitude 31°02’–31°20’ N and longitude 77°55’–78°40’ E), which represents the biogeographical zone 2B West Himalaya (Rodgers & Panwar 1988). The altitude varies from 1200 m to 6000 m. The Gangotri NP covers an area of 2390 km^2 harbouring the Goumukh Glacier, the origin of the River Ganges, and Govind NP covers an area of 953.12 km^2 encompassing the upper catchments of the River Tons. The climate of the area is the typical Western Himalayan climate, with medium to high rainfall during July-August at lower altitudes. The average rainfall is 1500 mm, and it is extremely cold, with three to four months of snowfall in winter, with a permanent snowline in the higher reaches.

Figure 1.



Study site. The work was conducted in three high altitude protected areas of Uttarakhand, India: Govind National Park and Sanctuary and Gangotri National Park.

The vegetation pattern in the study area resembled the broad pattern of vegetational zones of the north-western Himalaya (Champion & Seth 1968). The lower altitude represents the montane subtropical type, with Chir Pine (*Pinus roxburghii* Sarg.) dominating with the Tree Rhododendron (*Rhododendron arboreum Smith)*, Rohini (*Mallotus philippensis Lam*), Utis (*Alnus nepalensis* D. Don), Wild Pear (*Pyrus pashia* Buch.-Ham), Indian Laburnum (*Cassia fistula* Linn), Amla (*Emblica* officinalis Gaertn) and Toon (*Toona ciliata*,M.J. Roem). The shrub layer is dominated by Musk Rose (*Rosa moschata Miller*), a raspberry (*Rubus sp*.), Wig Plant (*Rhus sp*.), *Dodonea viscosa* Linn), *Colebrooka oppositifolia* Smith, *Pyracantha crenulata* M. Roemer and *Ziziphus mauritiana* Lam. The mid altitude regions had montane moist and dry temperate types of vegetation. Moist temperate vegetation consists of Grey Oak (*Quercus leucotrichophora* A. Camus), Blue Pine/Kail (*Pinus wallichiana* A.B. Jackson), Western Himalayan Fir (*Abies pindrow* Royle), Deodar (*Cedrus deodara* G. Don), Horse Chestnut *(Aesculus indica* Hook), Himalayan Cypress (*Cupresus torulosa* D. Don), and Yew (*Taxus baccata* Pilger). The shrub layer was dominated by *Viburnum continifolium* D. Don, *Hippophae rhamnoides* Rousi and *Berberis* species. The montane dry temperate vegetation zone was predominantly coniferous along with broad-leaved trees such as Oak, Ash and Maple. There were also Deodar, Juniper, High Level Fir (*Abies spectabilis* Mirbel.) and Silver Birch (*Betula utilis* D. Don). The subalpine zone, at around 3000 m, had dense coniferous forests, represented by species such as *Pinus wallichiana* A.B. Jackson) and Himalayan Yew (*Taxus wallichiana* Pilger) with intermixed broadleaved trees such as Kharsu Oak (*Quercus semecarpifolia* Smith). The common shrubs were *Rosa webbiana* Wallich, *Cotoneaster* sp., *Berberis* sp., etc. Herbaceous species such as *Delphinium* sp., *Swertia* sp. and *Pedecularis* sp. were found to be common. The *alpine meadow*, at 3300-3400 m, was mainly composed of Denthonia grassland interspersed with herbaceous plants such as *Potentilla, Pedicularis, Polygonum* and *Primula*.

MOTH SAMPLING AND IDENTIFICATION

We employed a stratified random sampling framework, *i.e*., random samples were taken from a gradient or stratum ranging from the lowest to the highest altitude zones, to record the patterns of moth community assemblages in both dominant and characteristic vegetation zones. Sampling occurred during three field periods (April-June 2010, October-November 2010 and July-September 2011). Moths were collected using a light trap running for 4 hours, from 7 pm to 11 pm, in the three seasons, *viz*, spring (April-May), summer and monsoon (June-July) and post-monsoon (August-November). Light traps were set using a solar powered lantern or gas petromax in front of a white 10' x 6' cloth sheet hung between two vertical poles in such a way that it touches the surface and extends forward over the ground slightly. After specimens were collected, they were killed using benzene vapour in a killing jar. The collected specimens were processed for pinning, setting and preserving in air tight wooden boxes. The specimens were first sorted into morphospecies and later identified with the help of the available literature and by comparison with the reference collections available at the Zoological Survey of India, Jabalpur and Kolkata. The classification used mainly follows Hampson (1892, 1894, 1895, 1896) and subsequent changes in the families based on Kirstensen (1999). The voucher specimens were submitted to the national repository at the Zoological Survey of India.

DATA ANALYSIS

Moths captured by light trapping at a single site for 2-3 nights were pooled for quantitative analysis. The species richness of moths of each vegetation zone, as well as of the regional data set, was measured according to the following four methods.

i. Species number: The absolute species number can never be the measure of diversity, particularly for such hyperdiverse taxa such as moths as it never incorporates different sampling sizes or efforts (Colwell & Coddington 1994).

ii. To avoid sample size dependence, using an extrapolation method, non-parametric estimators such as Chao 1 and Jackknife were estimated. Chao1 gives an estimate of the absolute number of species in an assemblage based on the number of rare species (singletons and doubletons) in a sample. Chao1 estimation of species richness is recommended for inventory completeness values, completeness being the ratio between the observed and estimated richness (Sørensen *et al*. 2002, Scharff *et al.* 2003). Jackknife estimators in general, and Jackknife2 in particular, have been found to perform quite well in extrapolation of species richness, with greater precision, less bias and less dependence on sample size than other estimators (Palmer 1990, 1991, Baltanás 1992, Brose *et al*. 2003, Petersen *et al.* 2003, Chiarucci *et al.* 2003).

iii. An individual based rarefaction curve was used to obtain an idea about the species richness and sampling success across different habitat categories. This method is particularly useful if assemblages are sampled with a different intensity or success. These curves standardize different data sets on the basis of the number of individuals and not on the number of samples. The curves were rarefied to the lowest number of individuals recorded in a vegetation type (198) to ensure valid comparisons of species richness between different sites (Gotelli & Colwell 2001). Rarefaction was used as a diversity index because it considers the number of individuals collected and species richness (Magurran 2004), allows comparison of diversity between sites with a similar sample size, and, by showing the rate of new species accumulation, allows verification that enough samples were collected to make proper comparisons of diversity (Gotelli & Colwell 2001, Magurran 2004, Buddle *et al*. 2005).

iv. The most reliable method for calculating the alpha diversity when it is impossible to obtain a complete inventory due to the presence of maximum singletons and doubletons is the use of Fisher's alpha of the log series distribution (Fisher *et al.* 1943).It has been widely used in tropical arthropod diversity studies. It is efficient in discriminating between habitats and is mainly influenced by the frequencies of species of medium abundance (Kempton & Taylor 1974). Bray-Curtis similarity coefficients, based on the Bray-Curtis similarity index for abundance data, which is a robust statistic particularly regarding the number and distribution of rare species, was calculated to categorize different sampling sites into broad vegetation zones and to look into the clustering of different vegetation zones in terms of similarity or dissimilarity of species assemblages. Indicator species were determined for all groups at different habitat clusters (from Bray-Curtis similarity coefficients) using Indicator Species Analysis (ISA) (Dufrêne & Legendre 1997). With this methodology, an indicator value is calculated for a species in each vegetation zone. ISA is a non-parametric technique in which the indicator value of a species is calculated as a product of the "faithfulness" (proportion of sites/ samples within the habitat in which the species is present) and the "exclusivity" (inverse of the total number of habitats in which the species occurs), expressed as a percentage. The values range from zero (poorest indicator) to 100% (perfect indicator). The statistical significance of the indicator values is estimated through Monte Carlo randomizations (999 permutations). At each level of cluster (species group), indicator values (IndVal) and their associated P-values of all moth species were calculated. Chao 1, Jackknife and Fisher's alpha were estimated using the Estimate S 8.2 (Colwell 2009) software package. Cluster analysis and ISA were performed using Program PC-ORD Version 4.2 (McCune & Mefford 2007).

RESULTS

SPECIES AND INDIVIDUALS

Sixteen families and 1992 specimens of moths were collected from the 20 sampling sites and were primarily sorted into 784 morphospecies, among which 1480 individuals could be assigned to the family level and 234 were identified up to the species level. The 20 sampling points (details of these are given in Table 1) were broadly grouped into six major vegetation zones, from lower to higher elevation zones: Chir Pine Forest, Agricultural Mixed Land, Mixed Riverine Forest, Broadleaved Mixed Forest, Conifer Forest and Alpine Scrubland.

Table 1.

Location, GPS co-ordinates, altitude (m), protected area and major vegetation zones of 20 sampling sites

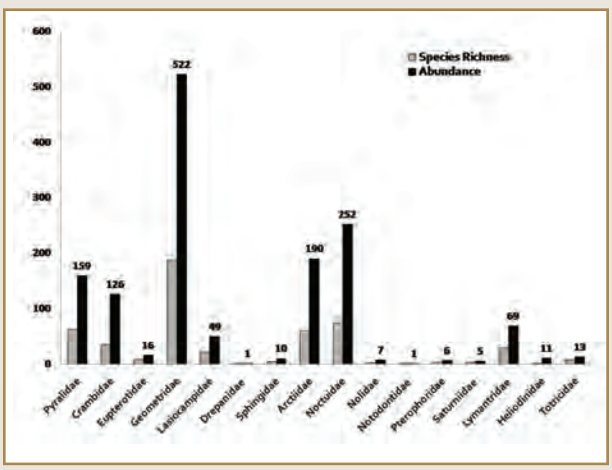
Sampling Site	Location	Protected Area	Altitude (m)	GPS Co-ordinates	Major Vegetation Zones
Chir Pine Forest	Naitwar	GWS	1450	31°04′07.5″ N 78°06′21.4″ E	Chir Pine
Riverine Mix Forest 1	Bhatwari	GNP	1530	31°04′07.5″ N 78°06′21.6″ E	Mixed Riverine
Riverine Mix Forest 2	Dhaula	GWS	1580	31°07′40.7″ N 78°02′41.0″ E	Mixed Riverine
Riverine-Broadleaf Mix	Jakhol	GWS	2100	31°06′7.7″ N 78°13′39.1″ E	Mixed Riverine
Low Agriculture Scrub	Naitwar	GWS	1450	31°04′07.3″ N 78°06′21.1″ E	Agriculture Mix
High Agriculture Scrub	Osla	GVNP	2600	31°07′09.8″ N 78°20′35.1″ E	Agriculture Mix
Broadleaf Mixed Forest 1	Harsil	GNP	2100	31°02′32.7″ N 78°44′51.7″ E	Broadleaf
Broadleaf Mixed Forest 2	Istragad	GWS	2100	31°07′40.7″ N 78°02′41.0″ E	Broadleaf
Broadleaf Forest 1	Haltadi	OP	2200	31°03′39.5″ N 78°07′38.0″ E	Broadleaf
Broadleaf Forest 2	Taluka	GWS	2200	31°04′03.0″ N 78°13′13.7″ E	Broadleaf

Disturbed Grassland	Chirwasa	GNP	3200	30°58′52.5″ N 79°01′17.0″ E	Agriculture Mix
Conifer Forest 1	Bhaironghati	GNP	2400	31°01′36.2″ N 78°52′04.7″ E	Conifer
Conifer Forest 2	Istragad T23	GWS	2450	31°07′24.0″ N 77°59′10.4″ E	Conifer
Conifer Mixed Forest 1	Istragad T25	GWS	2500	31°07′35.3″ N 78°01′31.7″ E	Conifer
Conifer Mixed Forest 2	Pustara	GWS	2600	31°04′03.6″ N 78°15′06.8″ E	Conifer
Rhododendron campanulatum P 1	Changsil	GWS	2300	31°07′24.0″ N 77°59′10.4″ E	Broadleaf
Rhododendron campanulatum P 2	Devgad	GNP	2300	30°59′44.4″ N 78°58′57.8″ E	Broadleaf
Juniper Scrub	Bhojwasa	GNP	3350	30°57′09.0″ N 79°03′01.7″ E	Alpine Scrub
Alpine Grassland 1	Har-ki-Dun	DVNP	3350	31°09′01.89″ N 78°25′ 44.74″ E	Alpine Scrub
Alpine Grassland 2	Gomukh	GNP	3850	30°55′33.0″ N 79°04′44.0″ E	Alpine Scrub

GWS, Govind Wildlife Sanctuary; GVNP, Govind National Park; GNP, Gangotri National Park; OP, outside protected area.

The number of moth species and the number of individuals trapped varied considerably between the vegetation zones, ranging from 118 to 261 species and 198 to 561 individuals. The family Geometridae was the most dominant family in all the vegetation zones sampled, with 522 individuals and 186 species, followed by the families Noctuidae (252 individuals and 74 species), Arctiidae (190 individuals and 60 species), Pyralidae (159 individuals and 62 species), Crambidae (126 individuals and 37 species), Lymantridae (69 individuals and 29 species) and Lasiocampidae (49 individuals and 21 species) (Figure 2). The other nine families, *viz.* Eupterotidae, Drepanidae, Sphingidae, Nolidae, Notodontidae, Pterophoridae, Saturniidae, Heliodinidae and Totricidae, had minor representations in terms of species richness as well as individuals.

Figure 2.

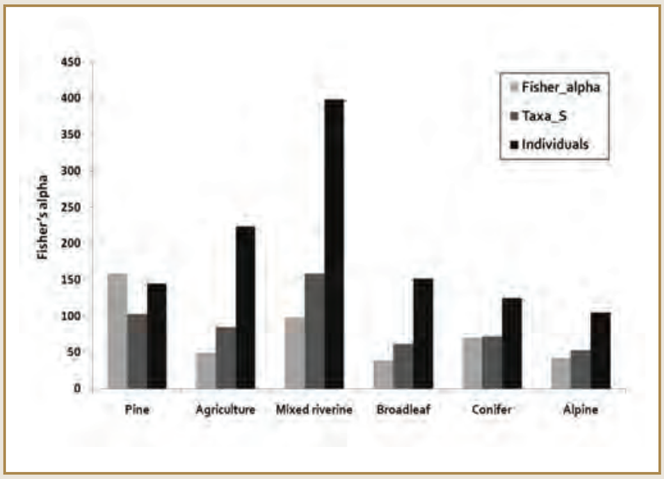


Species richness and abundance of 16 families recorded altogether in the study area. The family Geometridae was the most dominant family, followed by the families Noctuidae, Arctiidae and Pyralidae.

ALPHA DIVERSITY MEASURES AND HABITAT COMPARISON

Different diversity measures were calculated for moths in all the major vegetation zones for selecting a suitable diversity index. Among all the indices, Fisher's alpha performed most efficiently to discriminate between all the zones. Pine Forest (158.7) had the highest diversity, followed by Mixed Riverine Forest (97.86) and Conifer Forest (70.75). Diversity was low in rather homogenous habitats such as Alpine Scrubland (42.72), Agricultural Scrub (49.94) and Broadleaf Forest (39.07) (Figure 3).

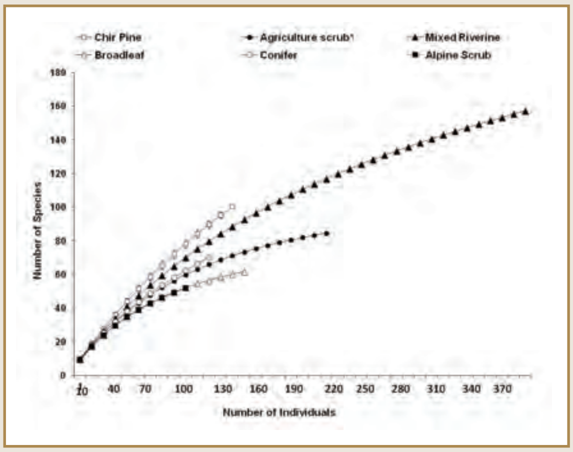
Figure 3.



Species richness, abundance and Fisher's alpha value at different Vegetation zones. The alpha value was highest in Chir Pine Forest and lowest in Broadleaved and Alpine Scrubland. Species richness and individuals recorded were highest in Riverine Forest.

As all the sites were sampled with different intensities, the rarefaction method was used as a suitable alternative for the diversity measure. Asymptotes were not reached in the species accumulation curves for any of the five zones except Agriculture Scrub, showing that a complete inventory had not been achieved. All the curves (Figure 4) lay within a relatively narrow band, and no clear pattern was visible. Sampling inadequacy was evident in all the vegetation zones. The rarefaction curves showed that Chir Pine Forest and Mixed Riverine forests had higher species richness compared with any other vegetation zone, Mixed Riverine emerging as a diversity hotspot. Diversity was lowest in Alpine Scrubland and Broadleaf Mix Forest.

Figure 4.



Individual based rarefaction curves to see the species richness and sampling success across different vegetation zones. Curves were rarefied to the lowest number of individuals recorded in a vegetation type (198) to ensure valid comparisons. Asymptotes were not reached for any of the five zones except Agriculture Scrub, showing that a complete inventory had not been achieved. Chir Pine Forest and Mixed Riverine forests have higher species richness than any other vegetation zone.

The total species richness estimated using Chao1 was 873 ± 12.32 (SD), and that estimated using Jackknife2 was 891 ± 11.82 (SD) for the complete sample (Table 2). The ratio of observed to estimated (Chao1) number of species was 90%, suggesting that at least 10% more species are to be expected in the area than were actually collected. However, at the local level, in Chir Pine, Broadleaf and Conifer Forest, we failed to collect such a high percentage of species (44% missing) compared with other vegetation zones (Table 2). From all species recorded, 153 were singletons (20% of all species) and 83 were doubletons (11% of all species). The highest species richness was found in the Mixed Riverine Forest (261 species), while the lowest species richness was in the Alpine Scrubland (118 species). The remaining four vegetation zones did not differ statistically in richness, considering the overlap of confidence intervals of richness value. The fraction of local singletons relative to species numbers recorded per site varied between 26% and 77%. The highest contribution of singletons was found in Chir Pine Forest, and this is the least successfully sampled vegetation zone (58% completeness). The Conifer and Alpine Scrub zones had lower proportions of singletons; these were lowest at sites with more regeneration or at early successional phases.

Table 2.

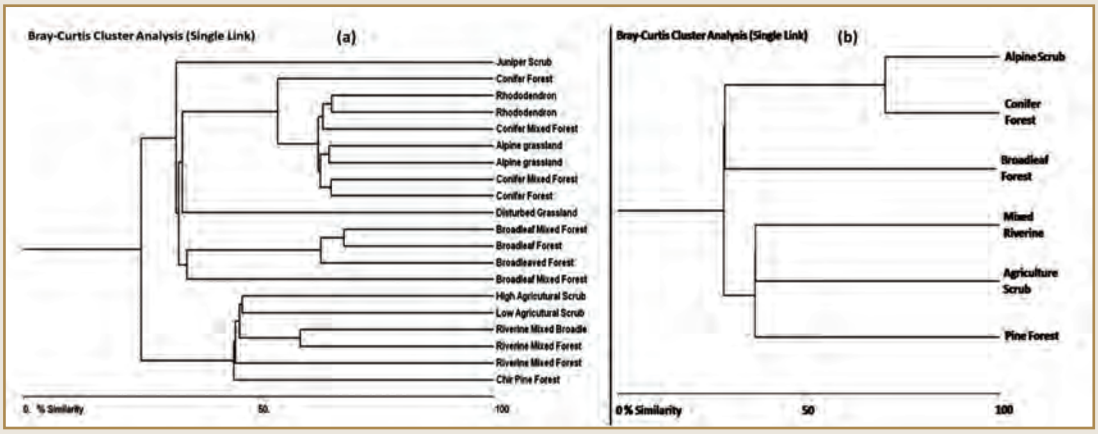
Measures of species richness estimates and inventory completeness for each vegetation zone and for the regional data set. Richness estimator values (Chao 1 and Jackknife2) represent the mean of 100 randomizations of sample order. The ratio of estimated and observed richness based on Chao 1 represents inventory completeness. All values rounded to the nearest integer

	Chir Pine	Agriculture Mix	Mixed Riverine	Broadleaf	Conifer	Alpine Scrub	Regional
No. of specimens	259	424	561	312	238	198	1992
Observed richness	190	161	261	137	146	118	784
No. of singletons	109	34	63	23	19	18	153
No. of doubletons	39	45	29	17	13	7	83
Chao 1	329	188	294	245	221	167	873
Jackknife 2	349	196	262	234	238	184	891
Percent completeness	58	86	89	56	66	71	90

SITES AND ZONES CLUSTERING

Although fine level discrimination was not visible at the site level (Figure 5) in the Bray-Curtis similarity coefficients, seven broad communities were visible. (i) All the agricultural scrublands, both high and low altitude, along with three Mixed Riverine Forest sites and Pine Forest sites, were clustered together. (ii) The Broadleaf Mixed Forest sites were separate altogether. (iii) Juniper scrubs and (iv) pure Conifer Forest sites formed two separate groups. The Conifer Mixed Forest sites formed two separate groups: (v) one with *Rhododendron campanulatum* scrub sites and (vi) another with alpine grasslands. (vii) Disturbed grassland sites, which were interspersed into Broadleaf Forest patches, formed a completely separate group. At the zone level (Figure 5b), the communities were well separated and made a gradient according to the elevational zones. While Pine Forest, Agricultural Scrub and Riverine Mixed Forest from the lower elevation band (1400 to 2200 m altitude) were clustered together, the higher elevational communities (2600 to 3500 m altitude) such as the Conifer Forest community and Alpine Scrubland community made separate clusters. Moreover, the Conifer Forest community and the Alpine Scrubland communities were the most closely related, with a similarity greater than 75% between them. The Broadleaved Mixed Forest, which lies from 2100 m to 2600 m in the study area, had a distinct community intermediate between the other two elevational clusters.

Figure 5.



(a) Sites and
(b) zone cluster from Bray-Curtis similarity coefficients: six major vegetation zones were identified from 20 sampling sites. At the zone level, the communities were well separated and made a gradient according to the elevational zones.

INDICATOR SPECIES ASSEMBLAGE

Indicator values of all moth species were computed for each vegetation zone, and only those species with statistically significant values ($P < 0.001$) were regarded as suitable indicators for a particular zone and are presented here (Table 3). Out of 234 species (unidentified morphospecies were not taken into consideration for presenting here), only 15 species performed well for their respective zones. Of all the vegetation zones, Mixed Riverine Forest and Conifer Forest were characterized by species with high indicator scores. Six species from the Mixed Riverine zone, *viz*. *Scopula pulchellata* Fabricius,1794, *Euproctis scintillans* Walker,1856, *Prodenia littoralis* Boisduval, 1833, *Spirama retorta* Clerck,1759, *Aletia medialis* Smith 1894 and *Gazalina apsara* Moore, 1859 and four species from the Conifer Forest zone, *viz*., *Epicrocis hilarella* Ragonot,1888, Spilarctia obliqua Walker 1855, *Glyphodes crithealis* Walker 1859 and *Pyrausta signatalis* Walker 1865 came out as good indicators. While less homogenous zones such as Pine Forest, Agriculture Scrubland and Broadleaved Forest showed generally low mean Indicator values, only one or two species remained “faithful” or “exclusive” to their respective zones. Alpine Scrubland was characterized by a single species, *Diarsia dahlii* Hübner, 1813, with a high indicator score.

Table 3.

Indicator species of moth in six major vegetation zones, along with their indicator values (Ind Val) and associated P values, as estimated by Indicator Species Analysis (ISA)

Species	Family	Ind Val	Significance (P)	Habitat
Psyra indica	Geometridae	57.5	0.001	Pine Forest
Lymantria concolor	Lymantridae	66.7	0.001	Agriculture Scrub
Terastia egialealis	Crambidae	66.7	0.002	Agriculture Scrub
Scopula pulchellata	Geometridae	100	0.001	Mixed Riverine
Euproctis scintillans	Noctuidae	100	0.001	Mixed Riverine
Prodenia littoralis	Noctuidae	100	0.002	Mixed Riverine
Spirama retorta	Noctuidae	100	0.001	Mixed Riverine
Aletia medialis	Noctuidae	100	0.001	Mixed Riverine
Gazalina apsara	Notodontidae	81.8	0.001	Mixed Riverine
Eoophyla peribocalis	Crambidae	66.7	0.002	Broadleaf Forest
Epicrocis hilarella	Pyralidae	100	0.001	Conifer Forest

Spilarctia obliqua	Arctiidae	100	0.001	Conifer Forest
Glyphodes crithealis	Crambidae	100	0.001	Conifer Forest
Pyrausta signatalis	Crambidae	83.3	0.002	Conifer Forest
Diarsia dahlii	Noctuidae	100	0.001	Alpine Scrub

DISCUSSION

The present study, a systematic inventory of moths, is the first of its kind in Gangotri Landscape and is one of the few studies on moth communities in India. As there is no previous species list available for this area, it is difficult to know precisely what proportion of the actual local and regional species richness the study captured. However, based on the estimated richness, the inventory was almost complete at the regional scale (90%). In spite of the relative success of this study, it still cannot be described as comprehensive – undoubtedly species were missed at local scales. Sampling additional sites or using different methods would capture more species. Additionally, lacking access to the modern equipments for light-trapping, we restricted our sampling to the understorey layer. Thus, species that predominantly or exclusively occur in the canopy were under-sampled. Moreover, the sampling efficiency was reduced in the dense forest vegetation. Therefore, capturing cryptic species in the dense vegetation zone is probably less complete compared with open zones. However, using a sample-size independent diversity measure such as Fisher's alpha (Hayek & Buzas 1997) should minimize distortions of between-zone comparisons. Nevertheless, the inventory protocol utilized here provided a sufficiently thorough samples of local and regional moth species to permit an accurate comparison of species richness of different vegetation zones. Overall, the moth assemblages varied among zones and revealed a pattern of assemblage response in relation to altitude and the related microclimatic regime of zones.

The moth diversity found was not similar in the different vegetation zones. Comparatively, Chir Pine and Mixed Riverine forests exhibit highly diverse assemblages, possibly due to their higher structural complexity. The relatively open and diverse overstorey and understorey structure of the Mixed Riverine forest supported the highest number of species, while the closed canopy Broadleaf Forest and agricultural sites supported relatively few species. In our study the proportion of unique singletons was 21%, but the fractions of local singletons mostly ranged around 30%. Singletons were more prevalent in the mature forest understorey. One plausible explanation for this high proportion is that species represented as singletons are "true forest species", which occupy special niches and occur at low densities. The moth composition in agricultural sites showed the most dissimilar assemblage in comparison with those of other vegetation zones. Possible reasons may be the scarcity of understorey vegetation, single species dominance, less complexity in vegetation structure and isolation from the nearest forest habitat, affecting the amount of different microhabitats available to moths. In conclusion, despite the small distances between the vegetation zones studied, the local ecological processes were strong enough to allow differentiation between moth species assemblages from mature forests and naturally disturbed sites. At disturbed sites the moth assemblages retained considerable diversity, even higher than in the mature forest, suggesting that landscape mosaics at the edge of nature reserves may support the survival of many of the more common species. Such areas could play an important role as buffer zones around protected areas (Schulze 2000).

The moth assemblages were structured among a gradient from lower elevational sites to high altitude alpine pastures. Two main moth assemblages were identified, which showed characteristic sets of indicator species for Mixed Riverine forest and Conifer forest. The other vegetation zones were characterized by only one or two indicator species, and no assemblage could be found for them. Though Pine forest was amongst the most species-rich zones in our study area in terms of both observed and estimated richness, the inventory completeness for this zone was only 58% (Table 2). It was also the zone where the second highest numbers of singletons and doubletons were recorded. This implies that there is still a good chance of recording more species here. This zone is characterized by open and high canopy forests with almost no undergrowth vegetation due to frequent burning events and a low flowering plant diversity except some scrubs at the edge. The openness of this zone may be the reason for cross-attraction of species from nearby habitats such as Agriculture Scrubland and riverine patches, which also signify the presence of only a single indicator species of moth, *Psyra indica* Butler 1889, with a low indicator score from this zone. The species of the genus *Psyra* are known to feed on the plant family Rosaceae (Robinson *et al*. HOSTS, Database of World's Lepidopteran Hostplants) which were abundant at the edges of the forest on frequently burnt slopes where there was plenty of shade and underground moisture. Agricultural zones are those with the maximum human interference and are characterized by a complex resource availability from an influx of rich minerals from anthropogenic activity. These are again open kinds of habitats where light trapping had a high chance of attracting species from adjoining habitats, and the species assemblages were dominated by common agricultural pests such as *Spilarctia obliqua* Walker 1855, *S. sagittifera* Moore 1888, *S. strigatula* Walker 1855, *Spilosoma erythrozona* Kollar 1844, *Argina multiguttatum* Hampson 1894, *S. sangaicum* Hampson 1894, *S. unifascia* Walker 1855 and *Helicoverpa armigera* Hübner 1827. Two species of moth, *Lymantria concolor* Walker 1855 and *Terastia egialealis* Walker 1855, were identified with a medium indicator score for this zone. These three species from Pine Forest and agriculture land can be considered as detector species, rather than indicator species, which are defined by moderate levels of fidelity and specificity. Changes in the abundance of these species may provide information on the direction of ecological change (McGeoch et al. 2002). In the Western Himalaya, climate change and human disturbance are causing the lower elevation Oak forests to be gradually degraded and invaded by the drought-resistant Chir Pine (*Pinus roxburghii*). So, long term monitoring of the increasing or decreasing abundance of these detector species of moth can be of great help for predicting the future direction of changes in forest structure in this fragile but ecologically important landscape.

Five species of moth of the highest possible indicator score (absolute indicator) and another with a considerably high score were identified from the Mixed Riverine Forest zone. The assemblage structure of this forest type is dominated by these species, and as a result of the variation in their optima, the relative abundances of these five species changed gradually along the main ecocline. Therefore, the composition of the assemblages changes principally according to the dominance structure of these species. The other species were in general more widespread, generalist or ubiquitous. The assemblage is characterized by the strong abundance of *Scopula pulchellata, Euproctis scintillans, Prodenia littoralis, Spirama retorta, Aletia medialis* and, to a lesser extent, by *Gazalina apsara*. This assemblage is typical of shady, dampy sites of primarily Oak forest (*Quercus incana* and *Q. galuca* contributing to the main canopy), with *Rhododendron arboreum* and *Lyonia ovalifolia* contributing to the second storey. The forest is currently facing considerable threat from lopping for fuel wood collection and extreme overgrazing, with grass patches developing due to the loss or breaking up of the canopy. The second assemblage, essentially consisting of Western Himalayan Coniferous Forest stands, is characterized by high numbers of *Epicrocis hilarella, Spilarctia obliqua, Glyphodes crithealis* and *Gonirhynchus signatalis.* These were both diverse assemblages and showed a lesser dominance structure in the distribution of species abundances. The vegetation of these sites is dominated by Blue Pine (*Pinus wallichiana*), Chilgoza Pine (*Pinus gerardiana*), Fir (*Abies spectabilis*), Silver Fir (*Abies pindrow*) and Spruce (*Picea smithiana*).These categories seem to be clearly structured along a vegetation gradient, showing various intermediate vegetation zones such as pure Fir forest (*Abies spectabilis*), mixed Oak-Fir forest (*Quercus semecarpifolia* and *Abies spectabilis*), mixed Rhododendron, Fir and Birch forest (*Rhododendron campanulatum, Abies spectabilis* and *Betula utilis*), and mixed coniferous forest (*Abies spectabilis, Pinus wallichiana* and *Picea smithiana*). All along this gradient, the composition of the moth assemblage changes gradually from sites dominated by *E. hilarella* and *G. crithealis* to sites dominated by *G. signatalis*. The ecological niches of the four indicator species are probably confined to a medium canopy with interspersed open, grassy patches, and they are rarely observed elsewhere.

Interspersed between Riverine Forest and Coniferous Forest lies the Western Himalayan Broadleaved Forest, which is characterized by both evergreen broadleaved forest, dominated by *Quercus semecarpifolia, Q. dilatata* and *Q. lamellosa* and deciduous broadleaved forest, dominated by *Ilex*, sometimes mixed with conifers such as *Abies, Picea* and *Cedrus* spp. It also has a dense understorey with mosses, ferns and several epiphytes on the trees. No true indicator species could be found here, with a single detector species, *Eoophyla peribocalis* Walker 1859, with a medium indicator score. Under-sampling with only 56% of the inventory completeness in this zone can be the probable reason. The alpine meadows of our study site were generally of a xerophytic formation, with the predominance of dwarf shrubs and under tremendous pressure from livestock grazing. These meadows were composed mainly of perennial mesophytic herbs, with very little grass on drier slopes. Conspicuous among the herbs were *Primula, Anemone, Fritillaria, Iris* and *Gentiana,* with Dwarf Juniper and *Rhododendron campanulatum* scrubs on the edges. The single and most faithful indicator species from here was *Diarsia dahlia* and the assemblage structure was characterized by an over-abundance of this species. The larva of this species primarily feeds on *Primula,* which can be cited as the most important reason for this assemblage pattern.

Although seasonal variations in the population size of an indicator species often hinder its use in monitoring habitat conditions, the use of only presence/absence data in our analysis resulted in unambiguous identification of true indicators that are always present (independent of their yearly abundance). Besides, year-to-year fluctuations, species assemblages can vary as a function of habitat conditions and landscape structure. The present analysis is based on an extensive data set from six zones representing different vegetation compositions so the determined indicator species can be used as bio-Indicators for future monitoring purposes. Our results suggest that the set of six moth assemblages identified as indicators may constitute a useful tool for conservation purposes. Focusing conservation efforts on the habitat requirements of these species may be beneficial in protecting a significant proportion of the Gangotri Landscape. These six groups are more or less specialized as ecological indicator species of the main gradient and are indicators of particular vegetation zones. Therefore, if we preserve and manage refuge sites for these species, we are likely to be providing protection for other organisms living in the same biotopes. Concentrating management practices on these six moth assemblages will also result in cost-effective administration of time and funding resources. The six sets of indicator species show features that make them ideal candidates for focal species. They may be assessed quickly using cheap and standard methods. Moreover, some of these species show narrow tolerances, and so they may be particularly sensitive to environmental changes (Oostermeijer & Van Swaay 1998). By using a multi-species approach, we are covering a long gradient of environmental conditions. These six sets of indicator species encompass the entire range of the studied biotopes. The simultaneous presence of many of these species may be an indicator of habitat heterogenity. The concepts of indicator and umbrella species may not be equivalent, and they may be interesting complementary tools for conservation practices (Fleishman *et al*. 2000). However, some particular species may constitute indicator as well as umbrella species. For example, the six sets of species identified as indicators have some characteristics that suggest they may be candidates for a suite of umbrella species. They are easily recognizable, show an intermediate degree of rarity, are moderately sensitive to human disturbance and encompass a large range of habitats (Fleishman *et al.* 2000, Maes 2004). However, to be considered as umbrella species, they must show a high pattern of co-occurrence with many other typical species, and that was not tested in the present study.

To conclude, because of the many advantages described above, we propose that these six moth assemblages can be used as indicators of vegetation zones and as surrogate species for conservation efforts. These species are habitat specialists of small size, and so they represent interesting tools at small spatial scales. The use of species assemblages as indicators may be considerably improved by extending the approach to organisms that are taxonomically and functionally different (Maes 2004). Future research should be oriented to integrate over larger spatial scales by incorporating knowledge from other taxonomic groups such as butterflies, beetles and birds.

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PLATE I : Some of the Moths of Gangotri Landscape

Psyra indica Butler, 1889

Terastia egialealis Walker, 1859

Scopula pulchellata Fabricius,1794

Spilarctia obliqua Walker, 1855

Glyphodes crithealis Walker, 1859

Prodenia littoralis Boisduval, 1833

Spirama retorta Clerck,1759

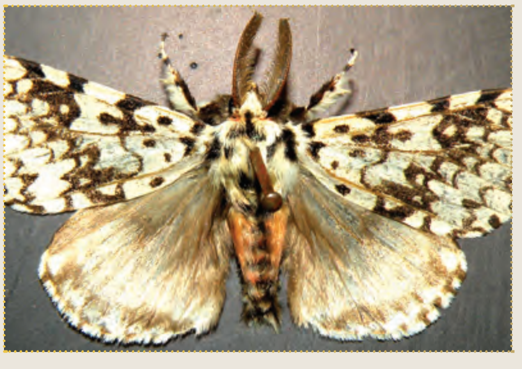
Aletia medialis Smith 1894

Pyrausta signatalis Walker 1865

Epicrocis hilarella Ragonot,1888

Eoophyla peribocalis Walker, 1859

Diarsia dahlii Hübner,1813



Lymantria concolor Walker, 1855

Gazalina apsara Moore, 1859

Euproctis scintillans Walker, 1856

IMPACT OF ENVIRONMENTAL CONDITIONS ON EGG LAYING BEHAVIOUR OF ERI SILKWORM, *CYNTHEA RICINI DONOVAN*

B.K. Negi and R.K. Pant
Eri Silkworm Seed Production Centre, Central Silk Board, Dehradun – 248 001, Uttarakhand,
email : drbknegi@gmail.com

ABSTRACT

Eri silk production has recently been introduced to the northern states of India. The first requirement is the availability of silkworm eggs and castor foliage. Production of eri silkworm eggs was started by the Central Silk Board through its Eri Silkworm Seed Production Centre (ESSPC) at Dehradun. The seed (eggs) production process is known as grainage work. During its initial year of egg production work, the ESSPC faced a lot of problems as the seasons that were favourable for seed production had not been established properly. Three important parameters, *viz*. moth emergence, number of eggs laid by each moth (fecundity) and hatching of eggs, decide the success of seed production work. Essentially the success of seed production depends on various external factors, important among which are temperature, relative humidity, etc. The present study was undertaken to establish the most suitable season for production of eri silkworm eggs. It was conducted at the ESSPC from 2007 to 2010, and all the five seasons, *viz.* spring, summer, rainy season, autumn and winter, were used for seed production. Season-wise data on the temperature, humidity, rainfall and moth behaviour (such as moth emergence, coupling, fecundity and hatching percentage) were recorded. From the study it has been inferred that temperature and humidity play vital roles in the successful production of eri silkworm eggs. There was a higher emergence (96.04%) of moths as well as higher fecundity (344.25 eggs/moth) in autumn. The lowest emergence (88.17%) and fecundity (216.50) were recorded during summer. So autumn is the best season for eri silkworm egg production, followed by the rainy season, in which the emergence and fecundity were 86.31% and 323.75 eggs/moth, respectively. Spring was found to be ideal for hatching percentage (92.50%), followed by autumn (91.50%). So the present work proved that temperature and relative humidity play important roles in the successful production of eri silkworm eggs. And these components have a significant correlation with the seasons.

INTRODUCTION

India produces all the four commercially known varieties of silk, viz. mulberry, tasar, muga and eri silks. Mulberry silk production is domestic in nature, whereas the production processes of the other three varieties are wild in nature. Eri,Muga and Tasarworms are called as Vanya silk as these silkworm sp. are wild in nature and found profoundly on the forest tree sp. In nature.presently these sail silk are cultivated by different tribes through rearing on the concerned plant species of the forest and their products are therefore termed as vanya silk (wild silk). Muga silk is produced only in the north-eastern states of India.

The World silk production is reported to 1,40,051 MT (2010), with India's contribution being 14.57%. With a production of about 23,000 MT, India is the second largest producer of silk in the world. China produces about 1,15,000 MT and therefore ranks number one in world silk production. About 4,423 MT of silk is contributed annually by Brazil, Thailand, Uzbekistan and Vietnam. There is a great demand for each type of silk in both the domestic and overseas markets. The white and brick eri silk is produced by worms of *Cynthea ricini*. The eri silkworm is polyphagous in nature, and therefore it has a number of food plants such as castor (*Ricinus communis*), kesseru (*Heteropanax fragrans*), tapioca (*Manihot utilissima*) and payam (*Evodia flaxinifolia*), but it is mostly grown on castor leaves. With the optimum temperature and humidity, the life span of the eri silkworm is 18-22 days.

PROCESS OF OBTAINING COCOONS FOR SEED PRODUCTION

To get eri silk, the silkworm larvae are reared inside houses and fed with leaves of their host plants, mostly castor leaves. At a certain period of time the larvae cast out their old skin. This depends upon the larval stage and is known as moulting. Each larva moults four times during its life cycle. At the end of the larval life span, the mature larvae stop feeding and start forming a shell known as a cocoon. The cocoon is formed to protect the worms from adverse climatic conditions as well as to provide a safe environment for metamorphic development, *i.e.* from the larva to the pupa inside the cocoon. In all three silk varieties,Mulberry Muga and Tasar the silk is reeled as a continuous filament from the cocoons, but eri silk is spun from cocoons because the silk secretion is not continuous during cocoon formation. Therefore at one point the cocoon remains open, and so eri cocoons are known as eri cut cocoons. The silkworm metamorphoses to the pupa inside the cocoon shell. The pupa remains inside the cocoon for about 15 days, and thereafter it metamorphoses into the moth. After the moth is formed inside the cocoon, it exerts a slight pressure at the open end of the cocoon using its antennae and emerges. After emergence, the male and female moth come together and start mating. The males start courtship behaviour, which is followed by copulation. The moths prefer to copulate early in the evening. The paired moths detach themselves under natural conditions. In commercial rearing, they are de-paired after a certain period of time. Each female moth is maintained separately for egg laying. Each female moth lays 300-450 eggs. Only the number of eggs laid by each moth over three days is considered in practice. The number of eggs laid by each moth depends on various factors such as the external environmental conditions, racial character, types of food plants used and the number of feedings provided during the larval life span. Reddy *et al.* (1989) recorded a maximum fecundity of 503.52 eggs from silkworm larvae reared on castor and a minimum of 222.92 eggs on Ailanthus altissima. Dearaj *et al.* (2003 reported fecundity values of 460, 311, 294 and 246 eggs/moth from moths of larvae fed on castor, payam, tapioca and kasseru, respectively. Under optimum temperature and humidity conditions, the eggs start hatching 10 days after they are laid. The number of life cycles completed by eri silkworms per annum depends on the atmospheric conditions and availability of foliage. Under controlled conditions, the number of life cycles can be increased.

The operations involved in eri silkworm seed production are known as grainage operations. These start with the procurement of seed cocoons from the seed cocoon growers and include sorting the cocoons using prescribed parameters, maintenance of the optimum temperature and humidity in grainage rooms, spreading the seed cocoons either in the form of garlands or uniformly on trays, allowing the moths to emerge, coupling, de-pairing, laying of eggs, collection of eggs, examination of eggs for disease, etc. Narayanswami *et al.* (1988) reported that a temperature of 22±2°C and a relative humidity of 70% were suitable for storage of seed cocoons and incubation. Gomma Ahmad (1972) and Gohain and Borua (1983) reported that temperature and humidity have a significant influence on the fecundity, incubation, hatching and pupation of the eri silkworm.

It has been observed that environmental conditions, more precisely the temperature and relative humidity, have a direct impact on the quality and quantity of eggs produced. So the present study was undertaken to study this impact. Grainage operations are more successful with a higher emergence of moths, higher number of eggs per moth and higher hatching percentage, and therefore the present study focused mostly on these three parameters.

METHODOLOGY

PLACE OF STUDY

The experiment was conducted at the Eri Silkworm Seed Production Centre (ESSPC) of the Central Silk Board, Dehradun, in Uttarakhand. Dehradun is bounded by the Sivalik Hills in the south, and the lofty Himalaya in the north. It is mostly cold in winter and moderately hot in summer. The temperature generally varies from 3°C to 39°C, and the annual rainfall is 1,700 mm. Most of the annual rainfall is recorded during the months from June to September. July and August are the rainiest months.

PROCEDURE

The main work of the ESSPC is to produce eri silkworms by following the prescribed procedure. For the purpose of the present study, 350 good quality cocoons were selected randomly from cocoons graded by the ESSPC. They were divided into five replications (lots), each lot having 70 cocoons. The cocoons were strung into garlands and hung on an iron frame inside a room at room temperature and ambient humidity. The moths were allowed to emerge. The temperature, relative humidity and rainfall data were recorded each season. The total number of moths that emerged each day was recorded separately (sex-wise). The behaviour of moths was also observed. They were maintained in partial darkness. The number of pairs that coupled each day was recorded. The coupled moths were de-paired 6 hours after pairing, and the female moths were kept for egg laying in a nylon netted bag. The moths were allowed to lay eggs for 3 days. After the third day, the eggs laid by each female moth were collected and counted. After the fourth day each female moth was examined under the microscope for assessment for protozoan diseases. When no protozoan spores were found, the entire lot of eggs laid by each moth was declared disease free. This is commonly known as Dfl, *i.e.* disease-free laying. The disease-free eggs were preserved at room temperature in petri dishes to observe their hatching behaviour.

PERCENTAGE OF PAIRING

To arrive at a conclusion, It is important to know how many moths emerged out of the total number of cocoons kept for seed production. To determine the male:female ratio, the number of pairs that were formed from a lot of emerged moths must also be known. Normally the male population is greater than the female population, but proper records were maintained to understand the seasonal behaviour.

The percentage of pairs was calculated using the following formula:

$$\text{Percentage of pairs} = \frac{\text{Total pairs} \times 100}{\text{Number of female moths that emerged}}$$

PERCENTAGE OF HATCHING

Twenty Dfls were selected randomly from the total number of Dfls produced in each season. The eggs were counted and placed in petri dishes at room temperature and ambient relative humidity for their hatching percentage to be observed. The hatching percentage was worked out from the following formula:

$$\text{Percentage of hatching} = \frac{\text{Total number of eggs that hatched} \times 100}{\text{Total number of eggs kept for hatching}}$$

The study was conducted during the summer, rainy season, autumn, winter and spring of 2007, 2008, 2009 and 2010. The mean of the mean values was calculated for all the seasons.

RESULTS AND DISCUSSION

METEOROLOGICAL OBSERVATIONS

From the weather conditions that were recorded during the study period, the season-wise maximum and minimum temperatures the relative humidity and the total rainfall received at Dehradun were calculated (Table 1).

Table 1. Mean weather conditions during the study period

Season	Maximum Tem (°C)	Minimum Tem (°C)	Mean Tem (°C)	Highest Tem (°C)	Lowest Tem (°C)	Relative Humidity (%)	Total Rainfall (mm)
Spring 16 Feb.-15 April	31.3 (1.63)	20.8 (1.96)	26.05 (0.97)	32.9 (2.21)	13.2 (3.94)	74.0 (8.78)	42.33 (51.90)
Summer 16 April-15 June	35.3 (1.92)	24.93 (1.58)	30.11 (1.76)	34.2 (2.04)	168 (4.64)	57.0 (6.68)	92.8 (72.35)
Rainy season 16 June-15 Aug.	30.5 (1.87)	29.7 (1.59)	30.1 (0.94)	30.8 (2.04)	22.3 (2.98)	87.5 (3.96)	629.5 (194.45)
Autumn 16 Aug.-15 Oct.	29.8 (1.08)	19.7 (1.89)	24.75 (1.38)	29.8 (1.98)	16.3 (2.63)	83.5 (5.36)	346.7 (103.79)
Winter 16,0ct-15,Feb.	21.8 (0.93)	7.6 (3.84)	22.0 (1.48)	24.8 (1.03)	7.6 (2.32)	87.3 (9.78)	20.2 (16.94)

BEHAVIOUR OF MOTHS

Data relating to moth behaviour, particularly with reference to emergence, coupling, eggs laid, and hatching percentage, are presented in Table 2.

Table 2. Data relating to moth behaviour

Season	Emergence (%)	Emergence (%)		Total	Un-emerged (%)	Coupling (%)	Fecundity	Hatching (%)
		Male	Female					
Summer	88.17 (8.43)	61.53 (10.84)	38.47 (10.84)	100	11.83 (8.43)	81.21 (2.21)	216.50 (41.74)	23.00 (21.04)
Rainy season	86.31 (9.86)	72.68 (3.83)	27.32 (5.64)	100	13.69 (9.68)	96.93 (2.02)	323.75 (27.63)	90,25 (3.31)
Autumn	96.04 (2.89)	62.95 (7.86)	37.05 (7.86)	100	3.96 (2.36)	96.43 (0.96)	344.25 (14.33)	91.50 (0.72)
Winter	93.94 (1.64)	62.18 (11.89)	37.82 (11.89)	100	6.06 (1,51)	96.57 (0.58)	223.00 (32.18)	87.00 (12.93)
Spring	94.42 (3.22)	66.91 (6.53)	33.09 (6.53)	100	5.58 (2.74)	96.23 (0.94)	326.00 (21.68)	92.50 (0.62)
Average	91.78 (5.62)	65.25 (6.04)	34.75 (5.38)	100	8.22 (3.98)	93.48 (0.86)	286.7 (28.56)	76.85 (1.98)

Values in parentheses are CD

It was observed that moth emergence started in the evening hours. The male moths were the first to emerge. The moths hung on to the cocoon shell till their wings were fully dried. They remained in a vertical position for 1-2 hours. After this drying period, the male moths became active than the females and started fluttering their wings rapidly and searching for female moths to mate with. Thereafter pairing took place, and the moths remained paired for 5-6 hours.

The emergence, coupling and fecundity were found to be influenced by the seasonal variations in the temperature, humidity and rainfall (Table 1).

The highest emergence percentage (96.04%) was found during the autumn season, and the lowest (86.31%) was found during the rainy season. The highest percentage (72.68%) of male moth emergence was noted in the rainy season, while the lowest (61.53%) was noted in summer. The highest emergence percentage of female moths (38.47%) was observed in summer, whereas the lowest (27.32%) was found in the rainy season. The percentage of emergence of male moths was always higher than that of female moths in all seasons. The highest percentage (96.93%) of coupling was recorded in the rainy season, while the lowest percentage (81.21%) was noted in summer. The females laid the maximum numbers of eggs (344) in autumn, whereas they laid the lowest (216) in summer. The highest percentage of hatching (92.50%) was observed in spring, and the lowest (23.00%) was noted in summer. It is inferred from the data that seasonal variations in temperature, humidity and rainfall have an influence over the moth emergence percentage, the fecundity (number of eggs laid by each moth) and the hatching percentage of the eggs (Table 2). A higher moth emergence is the key requirement for successful grainage. The highest emergence percentage was recorded during autumn, with the mean temperature being 24.75°C, the relative humidity 83.5% and the rainfall 347 mm. This indicates that the weather conditions of autumn favour a higher significant emergence. (1970) also observed that a high humidity and mild temperatures during grainage operations create moist conditions that expedite uniform development of moths and their smooth emergence. The lowest percentage of emergence was observed during the rainy season. During this season the mean temperature was 30°C, the relative humidity 87.5% and the rainfall 629.5 mm. These values were much higher than those of autumn, resulting in a low emergence of moths compared with autumn. This indicates that the optimal conditions are required for smooth and uniform emergence. The higher temperature, humidity, etc. of the rainy season might have disturbed the hormonal balance, resulting in a comparatively poor emergence. Similarly, in summer there might have been a high rate of evaporation of body fluid due to the low humidity and higher temperatures, adversely affecting the enzymatic activities and leading to a smaller number of moths emerging.

The highest percentage of male moths (72.68%) emerged during the rainy season, whereas the lowest (61.53%) emerged during summer. The environmental conditions prevailing during the rainy season seem favour the emergence of male moths. The lowe percentage of emergence of male moths during summer may be due to the higher temperatures and low humidity in the rearing environment. This might have led to dehydration in the pupae. Those moths that metamorphosed into moths might have lost their vigour and not been able to emerge from the cocoons. Ultimately they died inside the cocoons.

The percentage of emergence was observed to be the reverse in the case of female moths. Higher temperatures and relative humidity values induce the secretion of the eclosion hormone and elevate the secretion of the cocoonase enzyme in the female so that a greater number of females is found in autumn.

With regard to the number of eggs laid by each moth, the greatest fecundity (344.25 eggs/moth) was observed during autumn, and the lowest (216.5 eggs/moth) was observed in summer. In autumn, the mean values of the temperature, humidity and rainfall were 24.75°C, 83.5% and 346.7 mm, respectively, whereas they were 30.11°C, 57% and 92.8 mm, respectively, in summer. From the data it may be observed that higher temperatures (above 27°C) and humidity values (75 %) not only decrease the metabolic activity but also tend to decrease the egg production capacity of a moth. Thus it can be concluded that both low and high humidity values adversely affect the fecundity. Chowdhury (1970), Jolly et al. (1979), Gomma Ahmad (1972),and Sarkar(1995) also suggested the maintenance of optimum temperature and humidity conditions during grainage operations and provided norms for maintenance.

To get a good harvest of eri silk cocoons, one of the important requirements is to have quality eggs with a higher hatching percentage. The highest hatching percentage (92.50%) was obtained during spring, whereas the lowest hatching percentage (23%) was obtained during summer. During spring the mean temperature recorded was 26.05 ± 0.97°C, the relative humidity 74.0% ± 8.78% and the rainfall 42.33 mm, and the mean values of the temperature, relative humidity and rainfall recorded in summer were 30.11°C, 57% and 92.8 mm, respectively. It can be inferred that high temperatures and low humidity adversely affected the hatching percentage. So to have higher hatching percentages (more than 90%), a mild temperature (approximately 26°2) and a humidity value of around 75%5 is required. It has been observed that with an increase in the temperature and a drop in humidity, the hatching percentage decreased. It has been reported that when the temperature exceeds 30°C and the humidity falls below 60%, the eggs shrivel up and do not hatch due to the high rate of evaporation, which arrests the metabolic activities of the embryo. Finally the embryo dies inside the egg. Chapman (1978) reported that a low humidity is more harmful because the energy spent in maintaining the water content exerts a metabolic strain.

CONCLUSIONS

From this 3-year study, it has been found that ecological factors such as temperature, relative humidity and rainfall greatly influence the success of eri silk grainage work. Therefore the place where the grainage operations are to be undertaken will definitely affect the success or failure of the grainage work. Thus it the place needs to be looked into before grainage is established. The season is also equally important for its success. The emergence of moths was found to be highest (96%) and the fecundity was the highest (344.25 eggs/moth) in autumn. The hatching percentage of eggs was higher (92.50%) in spring.

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REVIEW OF INDIAN LEPIDOPTERA COLLECTIONS AND THEIR SIGNIFICANCE IN CONSERVATION

Peter Smetacek
Butterfly Research Centre, Jones Estate, Bhimtal, Nainital, Uttarakhand 263 136, India
email : petersmetacek@rediffmail.com

ABSTRACT
Indian butterfly and moth collections contain less than 50% of the estimated 11,300 species found in India. This deficiency has negatively impacted research as well as popularization and conservation efforts for this group of insects. The validity of governmental initiatives in this field is examined. Steps to improve the study of Lepidoptera in India are recommended.

INTRODUCTION
The process of naming the Lepidoptera is based on specimens. From the time that Linnaeus (1758) described the very first butterflies using the binomial system, pinned Lepidoptera have formed the basis of the science. The Linnaean collection of butterflies is in the custody of the Linnaean Society in London.

Specimens from all over the world, including India, were described on a large scale during the 19th century, so that by the 20th century, most of the commoner species had been described, sometimes under several names by different workers.

For the Indian Lepidoptera, much of this work was carried out in London. Collections in the custody of the East India Company and, later, the British Museum (Natural History), in London, and Lord Walter Rothschild's museum at Tring, housed vast collections of Lepidoptera from all over the world. Some Indian taxa were also described based on material in the Indian Museum, in Calcutta, by Lionel de Nicéville. These type specimens are the pride of the National Collection, at the Zoological Survey of India, Calcutta, today.

The process of defining species, distinguishing synonyms and separating similar looking species by examining the internal organs occupied most of the 20th century. Most of this work concerning Indian Lepidoptera was carried out in Europe, North America and, to a lesser extent, Japan.

The reason for this geographical bias is not far to seek – European workers had access to continent-wide or even global collections, while their Indian counterparts had access to nation-wide collections, mostly left over from the pre-Independence period.

At present, there are four important collections of Lepidoptera in India. These are the National Collection, at the Zoological Survey of India; the National Forest Insect Collection, at the Forest Research Institute, Dehradun; the National Agricultural Insect Collection, at the Indian Agricultural Research Institute, New Delhi; and the collection at the Bombay Natural History Society, Mumbai. There are collections of Lepidoptera, as well as other insects, at most agricultural universities in the country as well as at the Madras Museum and the National Museum of Natural History, New Delhi, but few of these are of any importance. The collection at the Punjabi University, Patiala, contains some type material and much recently collected material. Similarly, the collection at the Indian Institute of Sciences, Bangalore contains some recent material but nothing of particular importance. Besides, there are small, unidentified collections at the Forest Museum in Darjeeling and at the Jesuit Museum at Shembaganur near Kodaikanal. There are two private collections, one the Sircar Collection in Shillong and the second the Smetacek Collection in Bhimtal.

In addition to the above collections, there are a few smaller collections in various towns of India, such as a part of the Wynter-Blyth collection at St. George's Home, Ketti, Tamil Nadu, and the Patna Museum collection.

All these collections contain material collected in India, with the exception of the National Collection, which houses some South-East Asian material from the de Nicéville collection, and the Sircar collection, at Shillong, which houses some commercially available specimens from other continents.

METHODS

Over the past 25 years, I have sought out and examined Lepidoptera collections throughout India. It has not been possible to examine the National Collection, at the Zoological Survey of India, Calcutta, and the smaller collections at various agricultural universities throughout the country, the Patna Museum, the Madras Museum, etc. However, discussion with those who have seen these collections clarified that the smaller collections contain little that is unique, while the collection in the custody of the Zoological Survey of India, while it is extensive, is in relatively poor condition due to its age and the climate.

There are practically no reference collections of moths besides those contained in the four important national level collections mentioned above, the Punjabi University Collection and the Smetacek Collection.

RESULTS

A very rough estimate would suggest that less than 50% of the Indian Lepidoptera is represented in Indian collections. Approximately 70% of the total of around 1300 species of Indian butterflies is represented, and perhaps 40% of an estimated 10,000 species of moths is represented. The relatively high percentage of butterflies represented is largely in the National Forest Insect Collection, which contains approximately 3800 species of Lepidoptera (Dr. Sudhir Singh, pers. comm.), while the National Agricultural Insect Collection has 3302 species (Dr. V.V. Ramamurthy, pers. comm.), mainly moths. The Bombay Natural History Society Collection houses around 1500 species of Lepidoptera, half of them butterflies (Dr. Rahul Khot, pers. comm.).

It may be pointed out that reference collections should contain about eight pairs of each taxon so that the range of variation can be adequately covered (Evans 1932). In the National Forest Insect Collection, most species, especially the rarer ones, are represented by a single pair. So although the butterfly species count is greater than those of other Indian collections, the possibility of this collection being of taxonomic use for comparing potential new taxa is low due to the paucity of specimens. I experienced this difficulty in describing *Neptis miah varshneyi* Smetacek 2004, when I discovered that the National Forest Insect Collection housed only a pair each of *N. miah miah* and *N. miah nolana*, which did not cover individual variations, seasonal differences, etc.

DISCUSSION

Around 250 butterfly taxa have been described from India, the Himalaya and associated mountain ranges during the past 60 years. Of these, the first valid taxon to be described by an Indian citizen was *Neptis miah varshneyi* Smetacek (2004). Even this was described in consultation with the late Lt. Col. J.N. Eliot of the U.K., and the comparative material used was from Col. Eliot's collection and the Natural History Museum, London, rather than any Indian collection. No valid butterfly species has been described so far by an Indian in the post-Independence period. (The taxon *Ypthima kedarnathensis* A.P. Singh (2007) is not unlikely a synonym of *Y. hannyngtoni* Eliot.)

In moths, fewer than 50 taxa have been described by Indian workers, which is a pitiably small number compared with the number of moths described from the area during the post-Independence period by international workers, which is estimated to be over 700 taxa. In the period between 1990 and 2010, a dozen new hawkmoth species (Sphingiidae) were added to the Indian fauna. None of these were either reported or described by Indian workers. Rather, they were described by German, Japanese and British workers in the field (list available on www.flutters.org).

In the case of the giant silk moths (Saturniidae), 23 new species have been described and added to the known fauna of the sub-region comprising India, Bhutan, Nepal and Sri Lanka between 1993 and 2010. None have been described by Indian workers. Rather, they have been described by German, British, Russian and Chinese workers (list available on www.flutters.org).

The main reason for this discrepancy is that Indian workers are constrained by the lack of identified material available for comparison in India. The best collection of Indian Lepidoptera is at the Natural History Museum, London. It is, however, far from complete. The next best collection of Indian Lepidoptera is the Hope Collection at the University Museum, Oxford, which houses over 5 million insect specimens.

It should be noted that all the above collections consist largely of a mosaic of smaller collections donated by private individuals, either as presents or bequests. Inputs from agricultural scientists and foresters usually consist of species of immediate interest to their professions rather than compilations of the fauna of an area. For the latter, the usual source was from resident private individuals. For example, I have donated a large number of identified Lepidoptera from the Kumaon Himalaya to the national collections over the years.

It is only when collectors in different areas study the fauna of their area, note changes, obtain voucher specimens of rare species and communicate their findings that there is progress in the field. Government scientists usually manage much less time in the field due to the burden of desk work entrusted to them. Nor are they able to be in the field at odd times, seasons, etc, when rare creatures are usually sighted, since they have to justify their field trips on the basis of existing information and thus tend to conduct surveys at seasons when there are a greater number of species known to be on the wing rather than explore the unsurveyed seasons and areas.

In Nepal, where surveys have been actively undertaken over the years with international help, the figures speak for themselves: in 1978, 567 species of butterflies were known from Nepal. By 1980, this figure had risen to 592. Today, 640 species are known from Nepal. Of these, 58 species are unrepresented in Nepalese collections, i.e. the collections at the Pokhara Museum and the Natural History Museum, in Kathmandu (Smith 2006). This is less than 10% of the total number of butterfly species known from Nepal. Almost all these specimens were collected recently, *i.e*. within the last 40 years.

This rather respectable figure may be compared with the more than 30% of Indian butterflies unrepresented in Indian collections. Of the less than 70% represented, most specimens are around a century old and not in good condition. Of the taxa that are represented in Indian collections, roughly 40% of the species are represented by fewer than six specimens each in different collections, which is not enough to conduct any meaningful taxonomic studies.

In addition, these older specimens were usually collected by what were known as "native collectors", who were usually village boys trained to collect and preserve specimens. The specimens they brought back lacked proper data such as the date and locality, and so most of the butterflies they brought back are merely labeled "Assam" or "Sikkim". Both these places are very varied in terms of butterfly habitats, with the result that for a number of species, we have no idea of their preferred habitats or flight time (Wynter-Blyth 1957). It is only recently that enthusiasts armed with digital cameras have re-discovered a number of species that had not been reported for a century, such as *Symbrenthia silana* de *Nicéville (Nymphalidae)*, *Euthalia iva* Moore and *Creteus cyrina parca* de Nicéville (Hesperiidae).

In this respect, the current rules, laws and usages are heavily skewed against the collection of insects, whether for scientific use or other purposes. Prior to 1986, there was no bar on collecting insects. In that year, many butterflies and beetles were inexplicably included in the schedules of the Wildlife (Protection) Act 1972. No studies, surveys or other forms of information gathering appear to have been carried out prior to this exercise. Rather, the basis appears to be the status ascribed to the various species and subspecies in Evans (1932), so that those believed to be "very rare" by Evans were placed in Schedule 1, bringing them on par with the tiger, rhinoceros and other large mammals, while those believed by him to be "rare" were included in Schedule 2. This unreasoned approach led to the inclusion of the Pea Blue (*Lampides boeticus* Linnnaeus) and the Gram Blue (*Euchrysops cnejus* Fabricius) in Schedule 2, although they are known to damage leguminous crops and the Ministry of Agriculture has supported studies for controlling the populations of these butterflies. Prashanth Mohanraj and Veenakumari (1996) commented further on the shortcomings of the schedules in this Act.

Due to the grave lack of knowledge about insects at the policy making level, butterflies, moths and other insects have come to be viewed as "wildlife" and, bringing them on par with vertebrates, the emphasis is on the protection of the adult individual. However, butterflies live for a fortnight, spending most of their lives in the egg, larval and pupal stages. There is no provision for the protection of the early stages. This would entail protection of the habitats of the insect rather than the adult individual. This is not possible at the present time since we have no idea about the habitats of many lesser known species, which would arguably need protection most, if at all.

While collectors are viewed with suspicion, damage to habitats is being encouraged by various governmental ministries and departments, through cattle loans to marginal farmers and attempts to improve the genetic configuration and population of domesticated animals such as sheep, goats and buffaloes, with very little emphasis on reducing the dependence of this unjustifiably large cattle population on Indian forests and common lands.

With the inclusion of many butterflies and some beetles in the schedules of the Wildlife (Protection) Act 1972 and by imposing curbs on collections under the Biodiversity Act, the real issues of insect conservation have been ignored and, in fact, grievously side tracked. The main result of including some butterflies in the schedules of the Wildlife (Protection) Act has been that practically no studies have been published on those species since 1986. I can think of only two meaningful studies, those carried out by Veenakumari *et al*. (1997), in the Andaman Islands, and Singh (2009), in the Kedarnath Musk Deer Reserve, Garhwal. Other studies talk of catch-and-release methods for studying butterflies. Given the paucity of good reference books on Indian butterflies and the relative inexperience of the authors of such studies, such publications are at best unreliable, especially when one considers that the nomenclature of difficult groups is likely to change with the distinguishing of new taxa, but there will be no specimens to examine and apply the revised nomenclature since they were released at the time of the studies. Thus, invaluable time spent in the field and published results are reduced to unreliable statements due to unenlightened legislation.

Recently, there was a case where a worker in a protected area in Tripura found a butterfly that represented a new species record for India . He took it, photographed it and released it since, according to the rules governing protected areas, he could not take the specimen. The result is that, today, although we have a new addition to the Indian fauna, we do not have a specimen of the species. Surely, the rules would be more to the benefit of our nation if workers who discovered something new for science could take the specimen and hand it over to the person in charge of the protected area, who could be charged with forwarding the specimen to the Forest Research Institute so that it could become part of our national knowledge base? Meanwhile, agriculturists and pastoralists within such protected areas are legitimately doing much more damage than the taking of some insect specimens for research. Why is the uneducated villager permitted to do damage (read "cut fuel wood and fodder indiscriminately, graze livestock") and the educated researcher not permitted to do damage (read "take specimens of importance to science"), especially when the latter would be of long term benefit to our nation and little harm to the environment?

The lack of good reference books on Indian butterflies can be directly traced to the lack of collections on which such books are usually based. Today, the only work that covers all Indian butterflies is Evans (1932), with an outdated taxonomy and nearly a century old. For moths, the story is even worse, for the last work dealing solely with Indian moths is part of the Fauna of British India series, Volumes 1-4, by George Hampson (1892-1896), and Volume 5 of the same series, by Bell and Scott (1937). I am at present trying to make a list of Indian moths, and the task is proving extremely difficult and only possible with help from international experts. The first parts of this list, covering hawkmoths (Sphingidae) and giant silk moths (Saturniidae) are posted on the website www.flutters.org.

Although no Indian butterfly is known to be extinct, the only justification for this statement is that there are no studies on the relatively lesser known taxa, and their existence, in several cases, is yet to be confirmed. There are a relatively high number of endemic butterflies in the Himalaya and south India, around 8% of Indian butterflies, according to some estimates.

There is no conservation plan, no plan to tackle potential emergencies, no recognised pool of expertise to deal with challenges, no formal group of authorities who can take new developments into consideration and formulate appropriate policies, no empowered committee on Lepidoptera or even insects who can take up legal and legislative issues, no up-to-date literature on the subject, no complete, taxonomically up-to-date collection – in fact, the only thing that has been done for Lepidoptera appears to be legislation. While this legislation has prevented private enthusiasts from collecting insects, it appears to have had little effect on the international trade in Indian butterflies since many butterflies protected under Indian law are freely available on the Internet. So the end effect of including butterflies in the schedules of the Wildlife (Protection) Act 1972 appears to have been to hamstring Indian research on the subject and create a 20 year gap in our knowledge of the butterflies involved. International research has progressed, as noted above, in the cases of the butterflies, the hawkmoths and the giant silk moths.

From the above, it is evident that governmental efforts in the field of Lepidoptera research and conservation are a dismal failure. The efforts appear to be based more on the emotional and/or unsupported personal beliefs of concerned officials rather than the interests of our nation in particular or Lepidoptera in general. With the burgeoning human population and rapid scale of resource exploitation called development, the threat perception for many lepidopteran communities has increased many-fold. There is still time to consolidate what we have, but time is running out, and escapist policies and blanket bans simply do not work. What is needed is an educated approach to the long term conservation and proliferation of Indian insects.

RECOMMENDATIONS

It is urgently required that several complete collections of Indian Lepidoptera be made. Some projects are under way to improve Indian taxonomic abilities in the field of Lepidoptera, but these projects seem to be having little effect on the field in general. It is urged that rules and laws that give the government the sole right to undertake research in this field be amended to return the right to study insects to the people of India, as was the status before 1986. It is urged that the indiscriminate curfew on the field imposed in the name of conservation efforts by policy-makers and bureaucrats unfamiliar with the Lepidoptera be withdrawn and the opinion of persons familiar with the field be used to formulate policies in the best interests of the continued survival of Indian Lepidoptera. The excuse that there is a trade in Lepidoptera cannot be used to impose a virtual ban on this field. If the police were to impose an analogous curfew on the general public to prevent a few thieves operating, it would not be tolerated in any court of law. Why then should a similar, unjustified curfew that is detrimental to the interests of Indian Lepidoptera be imposed and tolerated?

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RARITY IN OAK FOREST BUTTERFLIES OF GARHWAL

Arun P. Singh
Ecology & Biodiversity Division, Rain Forest Research Institute (ICFRE), Jorhat, Assam
email : singhap@icfre.org

Butterflies are one of the important components of biodiversity and good indicators of environmental variation (Gilbert, 1980, 1984; Pyle, 1980; Brown, 1982; Murphy *et al.*, 1990; Kremen, 1992) as they are sensitive to any alteration in their habitats, the atmosphere, the local weather, the climate and light levels (Watt *et al*., 1968; Ehrlich *et al*., 1972; Weiss *et al*., 1987; New, 1991). The precise and restricted environmental requirements of particular butterflies make them of considerable value as a group of indicator taxa that indicate the broader effects of environmental changes or reflect a particular suite of ecological conditions (New, 1991). Besides, butterfly diversity also serves as a surrogate for plant diversity because butterflies are directly dependent on plants, often in highly co-evolved situations (Ehrlich and Raven, 1964). A greater number of butterflies usually implies a greater number of vascular plant species on which female butterflies can lay eggs. Butterfly assemblages are affected by habitat loss as native and specialized species decline and species feeding on weeds and those having high reproductive ratios increase (Shapiro and Shapiro, 1973). Butterfly species most representative of the original, pre-development, undisturbed butterfly fauna progressively disappear as sites become more degraded (Blair and Launer, 1997).

The western Himalaya, extending from Kashmir to Kumaon, support more than 417 species of butterfly (Wynter-Blyth, 1957). The area is unique as butterflies from both Oriental and Palaeartic regions mingle here. Ninety-one species among these have been listed as 'rare' or 'very rare', having been placed in schedules I and II of the Indian Wildlife Protection Act of 1972. The prime cause of their depletion in India is destruction of their natural habitats (Smith, 1989; Haribal, 1992).

The west Himalayan oaks *Quercus leucotrichophora, Q. dilatata* and *Q. semicarpifolia* occur in the 'moist temperate forest zone' of the western Himalaya, where they grow gregariously at altitudes between 1,200 and 3,300m, in pure and mixed stands. The Oak forest ecosystem is an important constituent of Himalayan biodiversity as these broad leaved trees provide food, water and habitat for a large number of wildlife species, being the larval food plants of at least six species of butterfly. Many associated trees, shrubs and herbs are hosts of more than 50 species of butterfly in this altitudinal range (Wynter-Blyth, 1957).

However, in Garhwal, these forests have now been extensively exploited and are today increasingly threatened by habitat degradation due to various biotic pressures from local villagers: lopping for fuel wood and fodder (Moench, 1989); grazing and browsing by cattle (Joshi *et al.*, 1996 forest fires (Champion and Seth, 1968; Sharma *et al.*, 1997); illicit felling for charcoal; landslides caused by deforestation and debarking of trees for tanning purposes (Haigh *et al.,* 1995); encroachment of forest land for agriculture; construction of roads and buildings; and other activities. The concomitant changes occurring in the natural Oak forest ecosystem as a consequence of these disturbances affects the structure and composition of the native Himalayan butterfly community present here. However, our knowledge of the native butterfly diversity of the Oak forests in Garhwal and the species occupying various habitat regimes in this ecosystem is negligible. Also, species sensitive to disturbance need to be evaluated for use as the best indicators for monitoring disturbances in these forests.

A 4 year (2006-2010) study was carried out in moist temperate forest areas of the Garhwal Himalaya (Dehradun, Tehri Garhwal, Rudraprayag, Uttarkashi and Chamoli districts of Uttarakhand) under an FRI/ICFRE project to identify the butterflies associated with oak forests and to evaluate species of conservation priority according to their rarity.

ECOLOGICAL CORRELATES OF SENSITIVITY

The community level responses of organisms to land use change are ultimately the consequences of how each species is adapted to its natural environment and how it responds to changes in biotic and abiotic factors following forest modification. Recently, the comparative approach has been used to investigate how traits possessed by species may predispose them to extinction (McKinney1997; Purvis *et al*., 2000). Such correlative analysis serves two important purposes in the context of land use change. First, it may allow us to identify preemptively species likely to be at risk from forest disturbance, using ecological traits that are easily measured or are readily available. Second, they may generate testable hypotheses as to why different species respond as they do to forest disturbance. Traits that are potentially important for butterflies include the geographic range, forest specialization, micro habitat specialization and larval host specificity (Koh, 2004). The degree of rarity characterizing a species is usually an indicator of extinction risk (Rabinowitz , 1981; Arita *et al.*, 1990; Primack, 1993; Gaston, 1994; Brown, 1995) In general, species characterized by a small geographic range, habitat specialization and low abundance are at higher risk of extinction than those that are widely distributed, that are habitat generalists and that have high abundance. Rare species are the focus of concern for conservation biologists. From a practical standpoint, rare species need to be protected and conserved, or they may become extinct.

SAMPLING METHODS

Four line transects of length 1 km each were chosen for sampling at each site. Each transect was trekked for 1.5 hours for sampling. For sampling butterflies, the standard 'Pollard Walk' methodology (Pollard *et al.*, 1975; Pollard, 1982; Walpole and Sheldon, 1999) was used. All the species that were encountered while trekking along the foot trails between these two sites were recorded daily. Voucher specimens were collected using a butterfly net for only those species that could not be identified in the field. They were also photographed for the same purpose.

A survey of the study area was carried out, and study sites were identified on the basis of the extent of Oak forest cover and the degree of disturbance (measured through the GBH, tree density, prevailing human disturbances, *etc.*). In this study 'rarity' analysis of all the butterflies species sampled in the Oak forests was carried out to identify those species that have a relatively (i) narrow geographical distribution range, (ii) habitat specificity to undisturbed oak forests, i.e sensitivity to disturbance, (iii) low abundance, based on the classification of Rabinowitiz *et al.* (1986).

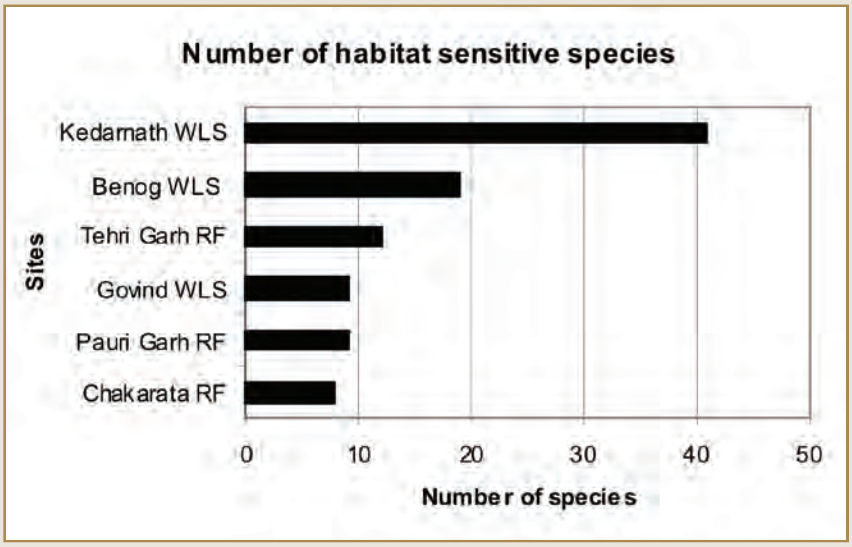
The moist temperate forest area of Garhwal, with three species of Oak, was taken up for this study. Six sites distributed all over Garhwal were studied during the 4 year study period (Fig. 1):

Figure 1.

Map of Garhwal depicting the location of the study sites mentioned in the text

1. Kedarnath Wildlife Sanctuary (Chamoli and Rudraprayag districts)
2. Govind Wildlife Sanctuary (Uttarkashi District)
3. Adwani and Chaurikhal RF (Pauri Garhwal)
4. Binog Wildlife Sanctuary, Mussoorie and surroundings (Dehradun District)
5. Chakrata Forest Division (Dehradun District)
6. Koti Kimoi; Dhanaulty; Nagtibba; and Budha Kedar-Pangarana area (Tehri Garhwal District).

Figure 2.



Distribution of species sensitive to disturbances in different Oak forest sites in Garhwal

RESULTS

Amongst the 211 species sampled, 61 species (Fig. 2) were determined to be sensitive to disturbance as their abundances decreased significantly ($p < 0.05$; Student's t-test)with disturbance in Oak forests.

Amongst these 61 species, 30 species (Table 1) were determined to be both rare (they had relatively restricted geographical distributions and low abundances) and 'sensitive to habitat disturbance' in Oak forests, as compared with the other species found there. These are thus the key butterfly species for conservation in the Oak forests of Garhwal.

Table 1.

Sl. No.	Species	Common Name	Flight Period	Larval Foo Plant	Forest Strata of Food Plants	Habitat Preference
1	*Atrophaneura dasarada ravana Moore*	Great Windmill	April-May	*Aristolochia* spp.	Shrub layer	Mixed forest
2	*Meandrusa sciron Leech*	Brown Gorgon	April-October	*Machilus duthiei*	Canopy	Mixed forest
3	*Aporia agathon caphusa Moore*	Great Black Vein	March-July	*Berberis* spp.	Shrub layer	Pure and mixed
4	*Euaspa milionia Hewitson*	Water Hair-streak	April-July	Data deficient	Middle storey and shrub layer	Pure

5	*Thecla ziha Hewitson*	White-Spotted Hairstreak	May-July	Data deficient	Middle storey and shrub layer	Pure and mixed
6	*Thecla ataxus Doubleday*	Wonderful Hairstreak	May-September	*Rhododendron arboreum*	Shrub and ground layers	Mixed
7	*Esakiozephyrus incana Moore*	Dull Green Hairstreak	May-September	Data deficient	Middle storey and shrub layer	Pure and mixed
8	*Chrysozephyrus syla Kollar*	Silver Hairstreak	May-September	*Quercus leucotrchophora*	Canopy and middle storey	Pure and mixed
9	*Chrysozephyrus birupa Moore*	Fawn Hairstreak	May-October	*Rhododenron arboretum*	Middle storey	Pure
10	*Chaetoprocta odata Hewitson*	Walnut Blue	May-September	*Jugalans regia*	Canopy	Pure
11	*Amblypodia dodonaea Moore*	Pale Himalayan Oak Blue	May-October	*Quercus leucotri-chophora* and *Q. dilatata*	Canopy and middle storey	Pure and mixed
12	*Panchala ganesa ganesa Moore*	Tailless Bush Blue	April-September	Data deficient	Middle storey	Pure
13	*Rapala selira Moore*	Red Himalayan Flash	April-July	Data deficient	Shrub layer	Mixed
14	*Chliaria kina Hewitson*	Blue Tit	March-October	Data deficient	Shrub layer and middle Storey	Mixed
15	*Lycaenopsis huegelii huegelii Moore*	Large Hedge Blue	April-October	*Prinsepia utilis*	Shrub layer	Mixed
16	*Dodona eugenes eugenes Bates*	Tailed Punch	February-October	*Arundinaria falcata*	Ground layer	Mixed
17	*Lethe verma verma Kollar*	Straight-Banded Tree Brown	April-November	Bamboos (Poaceae)	Ground layer	Pure and mixed
18	*Mycalesis lepcha lepcha Moore*	Lepcha Bush Brown	March-July	Data deficient	Ground layer	Pure and mixed
19	*Lethe baladeva aisa Fruhstorfer*	Treble?] Silverstripe	April-September	*Arundinaria falcata*	Ground layer	Pure and mixed
20	*Zophoessa goalpara narkanda Fruhstorfer*	Large Goldenfork	July-September	Data deficient	Middle storey	Mixed
21	*Callerebia hybrida Butler*	Hybrid Argus	April-August	Data deficient	Middle and ground layers	Mixed
22	*Ypthima kedarnathensis sp. nov.*	Garhwal Six Ring	May-October	Grasses (Poaceae)	Ground layer	Mixed
23	*Symbrenthia brabira Moore*	Himalayan Jester	April-November	*Debregeasia* sp.; *Elatostema* sp. (Urticaceae)	Shrub layer	Mixed
24	*Neptis ananta ananta Moore*	Yellow Sailor	April-December	Data deficient	Canopy, middle storey and shrub layer	Pure and mixed

25	*Neptis mahendra Moore*	Himalayan Sailor	April-October	*Flemingia* sp.; *Xylia* sp.; *Triumfetta* sp.; *Grewia* sp.	Middle storey and shrub layer	Mixed
26	*Neptis sankara sankara Kollar*	Broad-Banded Sailor	April-October	Data deficient Schedule II – Part II	Middle storey and shrub layer	Pure and mixed
27	*Neptis narayana narayana Moore*	Broadstick Sailor	April-October	Data deficient Schedule II – Part II	Middle storey and shrub layer	Pure and m ixed
28	*Neptis zaida zaida Doubleday*	Pale Green Sailor	April-June	Data deficient Schedule II – Part II	Middle storey a nd shrub layer	Pure and mixed
29	*Euthalia patala patala Kollar*	Grand Duchess	May-August	*Quercus leucotrichophora*	Canopy and middle storey	Pure
30	*Dilipa morgiana Westwood*	Golden Emperor	April-August	Data deficient	Middle storey and ground layer	Mixed

**For species 1,28,29 & 30, images are given in Plate- I*

LONG TERM MANAGEMENT OPTIONS

- The natural regeneration of oaks is adversely affected by lopping as no seed is set. Grazing and trampling by cattle, along with forest fires, destroys the seedlings in the under storey. A check should be imposed on repeated lopping of Oak trees. Since a lack of fodder tree species is one of the major causes of damage to Oak tree in the region, intervention by planting fodder trees and grasses in the fringes of villages may also be considered.

- Also, awareness may be generated amongst the villagers about the damage being caused by lopping to valuable Oak trees, which play a vital role in the Himalayan ecology, including recharging of ground water. Oak nurseries (*Q. leucotrichophora* and *Q. dilatata*) be established, especially in Govind Wildlife Sanctuary, Uttarakashi District, where the Oak stands close to the villages have been extensively exploited and there was practically no regeneration of Quercus leucotrichophora during the study period.

- Protection of selected oak forests stands against biotic interferences, mainly summer fires, felling of green trees and extensive lopping and grazing, .i.e. conservation of native habitat.

- Conservation of the larval food plants of the butterflies listed above.

- Protection of natural resources such as fresh water streams in Oak forests against pollution, mining and drying as a result of diversion as these are important habitats for butterflies in the dry summer.

- Amongst the plants exploited, there were also a large number of larval food plants of butterflies, which directly affect the life cycles of butterflies in Oak forests.

- This study therefore recommends that in order to conserve the Himalayan butterflies found in the Oak forests of Garhwal, managers and planners should aim to maintain the pre-developmental levels of butterfly diversity and check the disturbance in forest stands. Any further development in the moist temperate zone of the Garhwal Himalaya should be concentrated away from the land remaining under Oak forests.

PLATE I

The Grand Duchess, *Eutalia patala*

Golden Emperor, *Dilipa morgiana*

Brown Gorgon, *Meandrusa sciron*

Pale Green Sailor, *Neptis zaida zaida* Doubleday

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ROLE OF ENTOMOLOGY OUTREACH EDUCATION IN DEVELOPING INSECT INTEREST GROUPS IN INDIA: A BNHS INITIATIVE IN POPULARIZING ENTOMOLOGY

V. Shubhalaxmi and Isaac Kehimkar

Bombay Natural History Society, Hornbill House, Shaheed Bhagat Sigh Marg, Fort, Mumbai –400 001,
email : vshubhalaxmi@gmial.com

ABSTRACT

The Bombay Natural History Society (BNHS) has been conducting several entomological outreach educational programmes since 2000. These have increased awareness about insects. The programmes were largely conducted at BNHS Nature Reserve, in Mumbai; however, the connectivity with the target audience was countrywide. The range of approaches used by the authors was suitable for all age groups. These included walks, camps, special events, online course, hands-on activities, social media network groups, citizen science models and research projects. To support these activities, a range of educational materials were also developed. These included AV shows, field guides, exhibits, models, souvenirs and booklets. This paper documents the success indicators of the BNHS initiatives in popularizing entomology over the past 12 years. The outcomes of these initiatives have benefitted the audiences, authors and collaborators. The effectiveness of these efforts has generated interest among audiences who intend to pursue entomological studies or are pursuing them and contributed to insect conservation through education, tourism and community involvement.

INTRODUCTION

The BNHS has been largely known for its ornithological studies and publications, and now it largely focuses on vertebrates. Invertebrates were largely unexplored till 2000, when the authors designed the first Correspondence Course in Entomology. This gave rise to a series of outreach programmes that promoted insect awareness and developed a cadre of insect lovers. Overall, wildlife literacy in India is poor, and literacy about insects is poorer. So the authors strived hard to popularize entomology.

Today, the Conservation Education Centre (CEC) of the BNHS, in Mumbai, offers entomological outreach programmes about insects for the general public. The primary goal of these programmes is to promote entomology education. These programmes highlight the biology, ecology, diversity and novelty of insects to cultivate awareness about and appreciation of insects in the environment. These programmes extend beyond the traditional classroom to reach diverse audiences. Throughout the year, the Education Department faculty, staff and volunteers conduct insect-related programmes to children and adults at the BNHS Nature Reserve campus. These programmes provide school children and the general public with a great introduction to insect biology and ecology. The department also conducts 'live insect shows' at a variety of educational fairs and exhibitions. This paper documents the impact of BNHS initiatives in popularizing entomology through its outreach programmes.

STUDY AREA

On the event of its centenary celebration in 1983, the Government of Maharashtra had leased 33 acres of forested land to the BNHS, which is now known as BNHS Nature Reserve (BNR). The land is sandwiched between Sanjay Gandhi National Park and Film City. The forest is of a semi-moist deciduous type with rich floral and faunal elements. The CEC came into existence on this land in 1997. The terrain is undulating and thickly forested. There are five designated nature trails, which are used by 15,000 visitors annually. Most of the entomology outreach programmes were held at BNR. Insect activity is seen throughout the year, with different insect groups being active in different seasons.

OUTREACH EDUCATIONAL ACTIVITIES

The entomology outreach methods included a various interactive approaches and formats. Most of these programme modules were devised for the first time (for a summary, see Table 1.). The details of these methods are presented in the following paragraph:

BASIC COURSE IN ENTOMOLOGY (2000-2012)

This year course was developed in 2000 order to provide in-depth knowledge about the insect world to nature enthusiasts. In 2010, the correspondence course was converted into an online course by using Google Apps and Lore as course management software. A comparison of the course formats is given in Table 2. The course now offers online (asynchronous) learning in the form of monthly assignments and face-to-face (synchronous) activities such as online chat with experts, study of BNHS insect collection and field trips, which are interwoven through the course work. The participants are graded on the basis of their performance in assignments, project work and field trips and issued a certificate on successful completion, with appropriate grades. A total of 250 participants from 12 states have enrolled to date. The course is non-accredited; yet, the certificate has been accepted by foreign universities as an add-on year for the Indian graduates.The success of the course was presented as a poster in Communication and Education for Public Awareness (CEPA) Fair at the Conference of Parties (COP 11) held in October 2012 in Hyderabad.

INSECT PROGRAMMES

A range of programme modules were developed that were interactive and fun learning. The details are given in the following Paragraph:

BUG WALKS @ BNR (2011-2012)

During the year, seasonal insect walks were arranged at BNR. The aim of these walks was to infuse interest among the insects and banish insect phobias. These walks were usually held during weekends and lasted a few hours. Each month one seasonal insect was chosen. The walks were named after them, such as Cicada Walk and Red Cotton Bug Walk.

SPECIAL EVENTS

These include a unique half-day programme format that includes indoor and outdoor activities revolving around one theme. These are annual events designed according to the seasons at BNR. There were four such special events that were designed to glamourize the insect world. The details are given below:

BREAKFAST WITH BUTTERFLIES (2004-2012)

This unique annual event was inspired by the event held in Bronx Zoo, New York City, in 2003. It was first held in Mumbai in 2004. Since then it has been held every October. Till now 587 adults and 278 children have attended this unique event. The entire event revolves around butterflies and has a combination of indoor and outdoor activities. The sessions include the following: butterfly watching trail, illustrated talk on butterflies, butterfly photography, caterpillar rearing, gardening for butterflies, baiting for butterflies and butterfly quiz. Fun activities such as butterfly games, butterfly craft, face painting and treasure hunt are arranged for children. This is the most popular event at CEC and has received wide coverage on national TV channels. Film personalities such as Sonali Kulkarni, Shubhangi Ghokhale and Raghvendra Vasudevan attended this event on various occasions.

MEAL WITH MOTHS (2009)

This unique overnight event created a buzz in moth studies in India and made mothing popular. The event was attended by nine adults and seven children. The activities included an illustrated talk on moths, a nature trail and a mothing session with a light trap. The participants photographed the moths that visited the white sheet and grasped the moth family names with ease.

BASH WITH BUGS (2007)

This unique event is conducted every monsoon. Till now 106 adults and 41 children have attended this event. The sessions include an insect watching trail, illustrated talk, Kidagiri (locate insects in a terrarium), Ento-quest (quiz), Kidon ke Funde (ento-facts), Timtimate Jugnu (firefly light production mechanism), tips on keeping kitchens cockroach free and insect camouflage. Activities such as Insect Detectives, crosswords, treasure hunts and face painting are conducted for children.

INSECT CAMPS

The BNHS Programmes Department conducts regular butterfly/moth and insect camps for its members. The authors have been leading these camps. These include the following:

- Short-duration camps to Malshej Ghat, Bheemashankar Wildlife Sanctuary and Goa.
- Long-duration camps to destinations such as Namdhapha Wildlife Sanctuary, Nameri Tiger Reserve, Ultapani (in Assam), Sikkim and Bhutan.

CITIZEN SCIENCE MODULE

Under this category the first author has been training volunteers for insect studies. The details of these initiatives are given below:

BE A SCIENTIST FOR A DAY MODULE – INSECT AND MOTH SURVEY (2011-2012)

In January 2011, the CEC started a year-long biodiversity assessment of BNR with the title 'Be A Scientist for A Day'. The programme aimed at providing knowledge about field techniques to members of civil society. Insects were one of the biodiversity survey components. These monthly surveys include nocturnal surveys for moths and day surveys for diurnal insects. During the survey the participants helped with data collection. Moths and other nocturnal insects were studied using the light sheet method, in which a mercury lamp and white cloth are used. Analysis of the data from 2011 revealed that there had been 200 species of insect belonging to 15 orders, with the order Hymenoptera being the dominant order, while the Lepidoptera showed a greater species diversity. The programme was attended by 30 participants. The module became popular among schools and colleges. It was widely covered by many newspapers. Recently it has been covered by NDTV Greenathon, and Milind Soman participated in the insect survey.

VOLUNTEERS FOR MOTH STUDIES (2004-2006)

The first author selected three female entomology course participants and trained them to assist her in moth surveys. The team surveyed Sahyradri ranges for two years and developed a comprehensive paper on the moths of the northern Western Ghats. The listing presented an inventory of 419 moth species from 28 moth families belonging to 15 superfamilies. The paper is published in the Journal of the BNHS. Two other students were trained to collect life history data of moths from BNR Data are being collected over the past 3 years. Once the data are comprehensive, a joint paper will be published.

RESEARCH PROJECTS

Small research projects were designed to generate interest in insects.

PROJECTS FOR UNDERGRADUATES (2009-2012)

CEC recruits interns every summer. Those interns who show interest in field research are assigned small research projects at BNR. They included the following: study of ground-dwelling insects using the pit-fall trap method, study of food plants of cicadas, study of life-history of Red Cotton Bug and phenology of butterflies. While some of these studies yield interesting observations, not every project is completed due to various reasons. Nevertheless the interns get to learn about insect research through such small projects.

PROJECTS FOR STUDENTS OF HORNBILL NATURE CLUBS (2010-2011)

The BNHS's CEC has been establishing Hornbill Nature Clubs to support the environment education curriculum in schools. One of the club activities is a year-long project on local biodiversity. Insects are one of the easiest subjects to be seen in any urban area. The projects include a fortnightly or monthly insect survey in the immediate vicinities of schools and homes. The students carry out these surveys, collect data and enter them in data sheets provided by us. The BNHS team would then help the students in identification of insects. At the end the project, students analyse and present the data. The projects help students develop a better understanding about the role of insects role and get rid of their phobias.

PROJECTS FOR STUDENTS OF VACATION TRAINING PROGRAMME IN BIORESOURCES (2005-2006)

Under this 1 month long training programme, supported by the Department of Biotechnology, Government of India, research projects of students of standards X and XII students were planned. They included the following.

- Study of Swallowtail Butterflies of BNR
- Study of Pierid Butterflies
- Study of Nymphalid Butterflies
- Study of Milkweed Butterflies
- Study of Insect Homes Made Out of Soil
- Study of Insect Homes on Plants
- Study of Insect Homes Made Out of Body Secretions
- Study of Bugs
- Study of Ground-Dwelling Insects

EDUCATIONAL ACTIVITIES RELATED TO INSECTS

During the insect programmes mentioned earlier, a range of insect activities were devised and used:

- Be an Insect Detective. A game in which participants look for tell-tale signs of the existence of insects. They collect a variety of things that demonstrate the presence of any insect. A study kit is now being developed for schools.
- Pondipping for Aquatic Insects. The participants study aquatic insects by scooping a pond floor and identify insects with the help of an identification key. A study kit is now being developed for schools.
- Insect Quiz. There are several quizzes about insects that are used for a wide range of target groups. These quizzes are designed using the Kaun Banega Crorepati format, which brings in fun and interactivity.
- Insect Terrariums. Live insects and their relatives are kept in glass tanks. These tanks are used inside the classroom, where participants can view the animals and learn about them.
- Insect Skit. Several thematic skit plays were designed by the participants during course camps.
- How to have Cockroach-Free Kitchen. A poster demonstration on tips for eliminating cockroaches from kitchens.

ONLINE SOCIAL MEDIA GROUPS

With the advent of the Internet, many natural history e-groups have been established. The first author established two e-groups for interactions related to insects.

INSECTLOVERS YAHOO GROUP

http://pets.groups.yahoo.com/group/insectlovers/ (2000-2012)

The group was established along with the launch of the first entomology correspondence course. The purpose of the group was to provide a communication channel to all the course participants. It was used by the faculty as well as students to share and learn. Every year, a new batch of students was enrolled to the group. This practice was discontinued after the course became online. Currently, there are 258 members, and 4050 messages have been exchanged. This has been a closed group. There is not much communication now happening as most of the insect identification tasks are handled by another yahoogroup – InsectIndia – which was started by an Entomology Course alumna, Vijay Barve, who also established groups such as ButterflyIndia and DragonflyIndia.

INDIANMOTHS YAHOO GROUP

http://in.groups.yahoo.com/group/indianmoths/ (2005-2012)

The aim of the group was to popularize moths among the growing audience of butterfly lovers. It currently has 362 members, and 4029 messages have been exchanged. The first author enrolled international experts such as Dr. Roger Kendrick from Hong Kong and Dr. Ian Kitching from the U.K. These experts with their identification skills developed interests among amateurs who were keen to get their photographs identified. Understanding the demand, the first author established the group, but the moderation rights were given to Vijay Barve, who was keen to take this group under his e-groups banner, Diversity India.

EDUCATION MATERIALS (Table 2)

A range of educational resources were developed at the CEC by the first author to support insect outreach programmes for every age group. These included the following materials.

AUDIO-VISUAL SHOWS

A range of audio-visual (AV) shows was developed:

- Ek Kahani Titli Ki (A Story of a Butterfly): A 50-slide AV show on Indian butterflies was developed. The commentary was a jingle composed by the first author. The 7-minute jingle in Hindi was appropriate for smaller children. This became popular among children.
- Insect Mania: A 60-slide AV show on insects was developed in an interesting manner to orient any person with no knowledge about insects. It included trivia about insects and compared insects and human beings.
- Insect Classification: A 50-slide on insect classification was developed for the entomology course participants.
- World of Insect: An interactive multimedia presentation on insects was developed. This presentation provided basic and advanced information about insects. These levels ensure that the multimedia presentation could be used for a wide range of target groups.
- Moth Mania: A 45-slide AV show on moths was developed to orient people toward moths. This highlighted the basic differences between a butterfly and a moth and inroduced common moth familes.
- Insect Architecture: A 45-slide AV show on insect homes was developed. It was divided into three categories – subterranean, ground and tree insect homes.
- Plant-Insect Associations: A 50-slide AV show was developed. It was divided into two categories: (1) insects that use plants for food, shelter and defence and (2) plants that use insects for pollination, defense and food.

EXHIBITS

The CEC develops a range of exhibition materials for its own exhibition room as well as for other interpretation centres that it develops. The exhibit size varies from 3 × 4 square feet to 4 × 8 square feet.

EXHIBITS AT CEC'S EXHIBITION ROOM

1. Insect Architecture
2. World of Insects
3. Butterflies of BNHS Nature Reserve
4. Moths of BNHS Nature Reserve
5. Insects of BNHS Nature Reserve

EXHIBITS AT OTHER NATURE INTERPRETATION CENTRES

1. Insects of Malshej Ghat
2. Moths of Malshej Ghat
3. Insects of Mahableshwar

SOUVENIRS

Two souvenirs were developed, including a butterfly sticker sheet of 26 species and an insect badge for entomology course participants.

PUBLICATIONS

Every insect event was accompanied by a thematic booklet. The following major publications were also developed.

- Entomology Course Content: Altogether 28 chapters on entomology were developed. These were contributed by individual authors. Each chapter was 25-40 pages long. The content has been continually updated and provided to the course students.
- Field Guide Brochures: Three field guide brochures were developed for BNHS Nature Reserve. These were on butterflies, moths and other insects. Each field guide covered 60 commonly seen species. The insect and moth field guides were the first of their kind.
- Insect Educational Trunk: A mobile educational trunk on insects for secondary schools was developed. This trunk included an activity book, fact sheets, quiz cards, a flash card story, game cards, puzzles, puppets, a poster set on insect adaptations, the butterfly life cycle, camouflage and insect houses, a pond dipping kit, a caterpillar rearing kit, field guides and lesson plans. The trunk was used in classrooms, and a variety of activities were conducted.

INSECT MODELS

Two models were developed by CEC volunteers and course participants. The details are given below:

- Fire-fly Model: An electronic model to explain the light production in fireflies.
- Camouflage Model: An interactive model on Blue Oakleaf butterfly.
- Butterfly Chair: A butterfly chair has been developed for children.

PROGRAMME EVALUATION

As an evaluation of the BNHS initiatives in promoting entomology, an online survey was carried out among the participants who have been associated with BNHS for more than 10 years. The survey was taken up by 46 participants and here are the results.

PARTICIPATION IN PROGRAMMES (Figure 1)

The survey shows that a majority of participants participated on the insect walks (n=22%) and camps (n=22%) followed by special events (n=20%)such as Breakfast with Butterflies. This makes aggregate total of 44%. The participation in course work and other insect related activities accounted for 25% responses. A small percentage(n=11%) took up research related works such as project work and Insect Surveys during Be a Scientist for a Day event.

INSECT E-GROUPS (Figure 2 & 3)

A large number of participants were members of Butterfly India (n=72%) followed by Insectlovers (n=45%) and InsectIndia (n=45%). When the reasons for enrolling for these e-groups were analyzed, it was found 88% of participants mentioned learning about insects as prime reason for being part of these groups, followed 61% of participants mentioned meeting experts as a reason and equal percentage mentioned for socializing with like-minded people. A small percentage of participants (n=12%) wanted to develop a personal niche in entomology therefore they joined these groups.

FEEDBACK ON PROGRAMMES (Figure 4)

When the effectiveness of BNHS initiatives in popularizing entomology was analyzed against 8 parameters, it showed that 45% participants rated BNHS initiatives to be effective and 39% rated them to be very effective which makes an aggregate total of 89% effectiveness of the initiatives and remaining 11% rated them to be ineffective. On question, whether these initiatives will help in insect conservation, 99% respondents favourably.

BENEFITS TO PARTICIPANTS (Figure 5)

When the participants benefits were analyzed against the 11 parameters in three categories, it was found participants gained 63% personally, 20% academically and 17% professionally.

PARTICIPANT'S INITIATIVES (Figure 6)

When the participants' responses were analyzed for their contribution after being aware about insects, 58% participants showed willingness to contribute towards insect conservation, 30% participants were not sure and 12% were not keen. Among those who showed willingness it was found 42% participants wanted to work for insect education and 38% wanted carry out entomological research. Of which 34% exclusively wanted to work in education creating awareness, 33% wanted to work for insect conservation through education, 25% wanted to develop insect publications, and remaining 8% wanted to work in promoting butterfly tourism.

INDICATORS OF SUCCESS

The success of BNHS initiatives could be gauged from the success of participants as well as the authors who excelled in their respective fields. Some examples are mentioned below:

Success of Entomology Course Participants

- Nelson Rodrigues, a copywriter who started his first brush with insects 8 years ago when he enrolled for the entomology course. He got fascinated by butterflies and second author became his role model. This inspired him to write his first book- Butterflies of Mumbai.
- Rishiddh Zaveri was a class XI student when he joined the entomology course, his interest in entomology grew in his grooming years as he was mentored by the first author. He completed his post graduation in environmental sciences and now works as an environmental consultant with specialization in insects.
- Alka Vaidya, a housewife who completed her entomology course in 2001 and then in 2004 volunteered on the moth project of the first author and readily pursued her moth studies beyond the project period wherein she surveyed moths of Eaglenest Wildlife Sanctuary for Kaati Trust. She continuous to survey moths of North-eastern states of India.
- Alaka Bhagawat, a housewife who completed her entomology course in 2003, joined as volunteer for the moths' project of first author in 2004, thereafter she pursued her Ph.D in butterfly gardening.
- Sheila Tanna, an Ophthalmologist who completed her entomology course in 2003, got new record of Common Jay Butterfly for Mumbai
- Vijay Barve, an IT professional when he joined entomology course in 2002, now pursuing doctoral studies in Geography at University of Kansas. He established highest number of e-groups (12 yahoogroups and Facebook groups) on natural history subjects. His first group being Butterfly India established in October 2001 which is the most popular among all the groups

Success of Participants of Insect Programmes

- Rajendra Ovalekar,a school teacher who established the first open-air butterfly park in Thane after attending Breakfast with Butterflies event at CEC in 2004. The garden is visited by 4000-5000 visitors annually.

Success of Authors

- The entomology course module was accepted as first non-degree entomology course in the world. The paper was presented in 22rd International Congress of Entomology in Brisbane, Australia
- Volunteers for moth studies were developed and first joint paper alongwith volunteers is being published
- Breakfast with Butterflies event has become a branding event for BNHS, however many other organization have now started conducting these events in other parts of the country. The event received thorough media coverage on NDTV and IBN Lokmat channels
- Developed professional contacts with moth experts from the world; Dr. Jermy Holloway and Mr. H.S.Barlow from Malayan Natural History Society, Dr. Ian Kitching from Natural History Museum, London, Dr. Roger Kendrick from Kadoorie Botanical Gardens, Hong Kong and Dr. Shen-Horn Yen, University of Taiwan. These experts played an important role in providing help with moth identification and promoting mothing interest among Indians through the e-groups. The first author has collaborated with Dr. Kendrick for two joint papers on moths. Dr. Ian Kitching has agreed to become BNHS referee for moth papers. The collaboration got strengthened when Dr. Kendrick held the third Asian Lepidoptera Conservation Symposium at Coimbatore in 2010, which was first of its kind for India.
- Along with Vijay Barve and Dr. Kendrick the first author has initiated National Moth Monitoring Programme through Facebook group on Indianmoths. Through the programme, amateurs around the country are encouraged to set up mothing sheets every new moon night to attract and photograph moths. The moth pictures are then uploaded on a

Flickr group site which are then identified by the experts. The aim is to develop a pool of moth photographs which will help to prepare a quick checklist of Indian moths. This programme is under progress.(visit http://www.flickr.com/groups/indianmothsmonitoringnetwork/)

- Through the Butterfly India e-group, the first author came acrosss a new Zygaenid moth which was mistakenly posted as a butterfly by Mr. Punyo Chadha, a school teacher in Arunachal Pradesh. The first author was able to conduct a rapid survey for the moth with help of Mr. Chadha. The search of new moth is still in process.

Success of Collaborators

- Dr. Ian Kitching, a Hawkmoth specialist at Natural History Museum at London mentions that his association with indianmoths yahoogroup from 2005 till to date has added 112 new records for moth species from India. This data is now part of his project; Creating a Taxonomic e-Science (CATE).

DISCUSSION

The paper successfully documents more than decade efforts of BNHS's entomology outreach programmes in promoting entomology. These initiatives that are divided into eight categories have used a variety of approaches that is suitable for all target audiences. All programmes and events mentioned herein attracted a small number of audiences as not many people are keen to learn about insects, however on regular basis a small population of audience got rid of their insect phobias specially children. It has been observed that brain teasers on insects were effective in attracting people's attention. Also nick names given to the authors such as bug lady, moth lady and butterfly man added charm to the programmes and interesting titles such as Breakfast with Butterflies, Bash with Bugs, Cicada Walk and others helped publicity of these programmes. The role of media in popularizing entomology has been crucial, especially when one newspaper covers a photo feature on insects, other news papers follow the league. This combined effect benefits the insect popularity. It was important that insect information was given in a lucid and interactive manner. Analogies played an important role in explaining the complexities among the insect world. The usage of educational aids also made an impact (Fig.6.).

Bird watching has become synonymous with BNHS, however with advent of butterfly watching which was primarily made popular by the second author, a new batch of butterfly lovers emerged who now compete with the birdwatchers in numbers and enthusiasm. When butterfly watching reached to its prime, it was time for mothing to make presence felt. After the advent of Indian moths yahoo group, awareness about moths grew and today butterflies and moths share equal importance among the target groups who realized the dual benefits of photographing butterflies during day and moths by night. When it came to photography insects proved to be best subjects due their easy availability and diversity in shapes, sizes and colours. It was seen that people were keen to get their photographs identified and there was a constant quest for common names as most of the insects do not have one.

It has been observed that absence of field guides on insects is the main reason why many do not take interest in observing insects. After the launch of second author's butterfly book, a cadre of new butterfly enthusiasts was born who joined the already growing bandwagon of butterfly lovers across the country. Due to internet access, information from remotest areas was easily available and people were able to connect with the experts more easily. A similar guide is required for different insect groups and the first to follow will be moths. As of now, the field guide brochures on insects and moths are filling in the gap.

There is an urgent need of young workers in the field of entomology as there exists a generation gap between the stalwarts' of entomologists and new generation of insectlovers. There is a need of role models, mentors and research guides. More importantly equal weightage need to be given to entomology in colleges and universities so that entomological research are not confined to agricultural pests and insects of economic importance, ecological researches are undertaken. With the international experts on the board, enthusiastic young members supported by dedicated mentors at BNHS, the indianmoths/Butterflyindia group will soon revolutionize the way lepidoptera studies are conducted in our country. The entomology outreach programmes has been successful to fast track the insect documentation of India through various interest groups that are scattered all over the country.

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We wish to primarily acknowledge late Shri. Naresh Chaturvedi, Curator at BNHS and guide to first author. His support in designing the entomology course was very crucial. We wish to thank all our course/programme participants who helped us with the survey and provided us with their important inputs. These include Chinmayi S K, Vandana Thakur, Jaykant Saini, Akshat Mullerpatan,Sanjay Marathe,Poorvi Raghavendra, Purnima Palekar, Nelson Rodrigues, Judhajit Dasgupta, Mehul Vasanjibhai Dedhia, Sanjeev Asher, Dr. Sanjyog Rai, Neelima Kalgi, Sanjay Sondhi, Viren Vaz, Dr. Suresh Jagtap, Subodh Juwatkar, Alaka R. Bhagwat and Sunila Navalkar. A special thanks for our international collaborators; Dr. Ian Kitching and Dr. Roger Kendrick for being mentors to many of our participants virtually. Lastly we thank the education team at CEC and volunteers of CEC who have played a key role in during the execution of the entomology outreach activities.

Table 1. Summary of Entomology Outreach Activities

Category	Name of the Activity
Course	Basic Course in Entomology (online)
Walk	Bug Walks @ BNR
Camp	Short-duration camp Long-duration camp
Special event	Breakfast with Butterflies Bash with Bugs Meal with Moths
Citizen cience	Be A Scientist for A Day module – Insect and moth survey Volunteering for moth studies
Research project	Projects for undergraduates Projects forstudents of Hornbill Nature Clubs Projects for students of Vacation Training Programme in Bioresources
Interactive activity	Be an Insect Detective Pondipping for Aquatic Insects Insect Quiz Insect Terrariums Insect Skit How to Cockroach-Free Kitchen?
Online social media group	Insectlovers yahoogroup Indianmoths yahoogroup

Table 2. Comparison of Entomology Course Formats

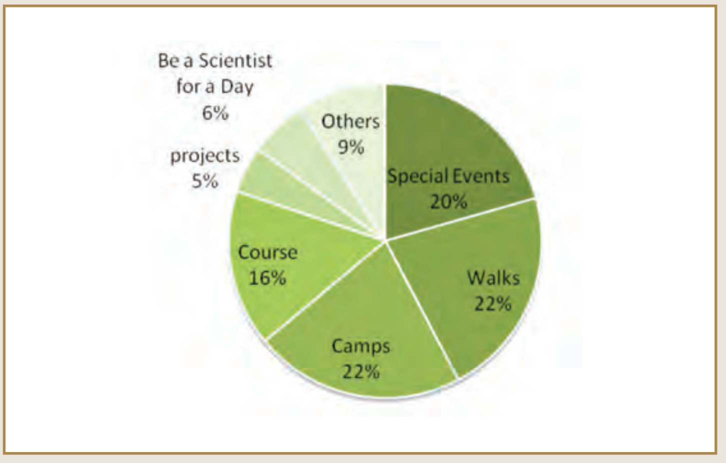
Course Components	Correspondence Course	Online Course
Number of chapters	28	12
Delivery of chapters	Post	E-mail
Presentation of chapters	B/W	Colour
Powerpoint presentations	Yes	Yes
Number of field camps	4	3
Number of field outings	6	5
Local insect project work	Yes	Yes
Open book examination	Yes	No
Visit to insect collections	Yes	No
Experts chats	No	Yes
Entomology news	No	Yes
Research paper review	No	Yes
Photo-sharing	Yes	Yes
Camp report submissions	No	Yes
Course inaugural camp	Yes	Yes

Valedictory function	Yes	Yes
Graded course	No	Yes
Certificate of completion	Yes	Yes
First started in	2000	2010

Table 3. List of Insect Educational Resources

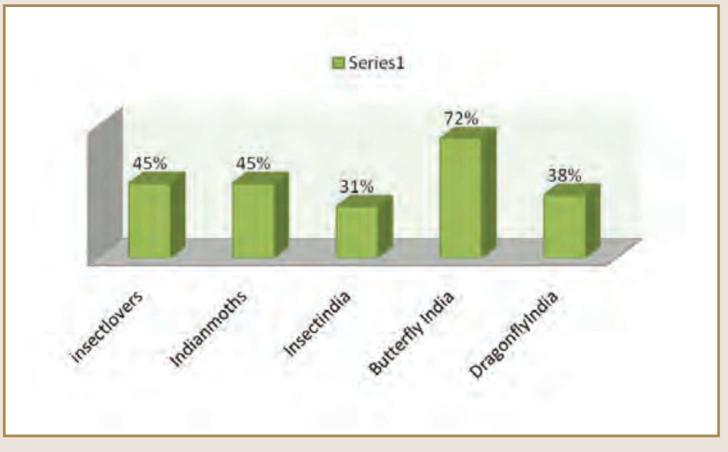
Category	Name of Educational Resource	Numbers
Audio-Visual Shows	Ek Kahani Titli Ki (A Story of a Butterfly)	8
	Insect Mania	
	Insect Classification	
	World of Insect	
	Moth Mania	
	Insect Architecture	
	Social Insects	
	Plant-Insect Associations	
Exhibits	Insect Architecture	8
	World of Insects	
	Butterflies of BNHS Nature Reserve	
	Moths of BNHS Nature Reserve	
	Insects of BNHS Nature Reserve	
	Insects of Malshej Ghat	
	Moths of Malshej Ghat	
	Insects of Mahableshwar	
Souvenirs	Butterfly sticker sheet	2
	Insect badge	
Publications	Entomology course content	5
	Field guide brochure on insects of BNR	
	Field guide brochure on butterflies of BNR	
	Field guide brochure on moths of BNR	
	Insect educational trunk	
Insect models	Firefly model	2
	Camouflage model	

Figure 1.



Participants and programmes

Figure 2.

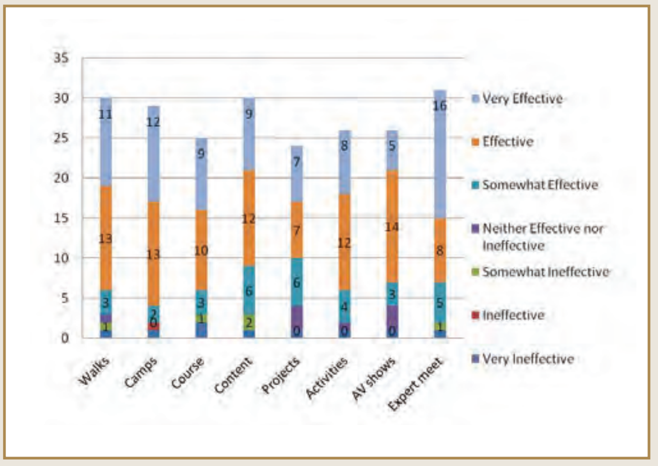


Members of e-groups

Figure 3.

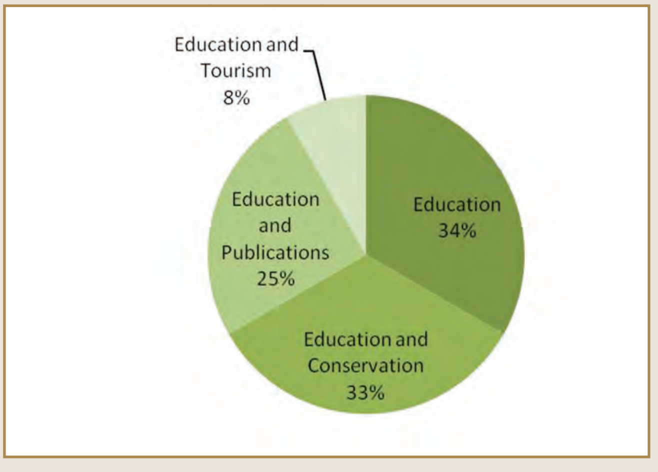
Expectations of participants of the E-groups

Figure 4.



Feedback on Programmes

Figure 5.



Participants' Initiatives

Figure 6.

Participants viewing insects in a special two-way magnifying lens jar

SPIDER FAUNA IN THE FOREST AND AGRICULTURAL ECOSYSTEMS OF CENTRAL KERALA, INDIA

***P.A. Sebastian*[1], *M.J. Mathew*[1] *and S. Murugesan*[2]**
1. Division of Arachnology, Department of Zoology, Sacred Heart College, Thevara, Kochi – 682 013, Kerala
2. Division of Bioprospecting, Institute of Forest Genetics and Tree Breeding, Forest College Campus, R.S. Puram, Coimbatore – 641 002, Tamil Nadu
email: drpothalil@rediffmail.com

ABSTRACT
Investigations were carried out on the spider species compositions in the forests, as well as rice, vegetable (bitter gourd, snake gourd, ivy gourd, cowpea and cabbage) and coconut agroecosystems, in Ernakulam, Idukki, Trichur and Palghat districts of central Kerala, India. A total of 169 species of spiders belonging to 82 genera and 24 families were sampled from the various ecosystems in central Kerala during the study. A total of 35 species were unique to the forest ecosystem, whereas 49 species were unique to the agricultural ecosystems. Eighty-five species were shared by both the ecosystems. A total of five new species were discovered during this investigation. Further, at the generic level, four genera, and at the species level, six species have been reported for the first time from India. A total of five species recorded from the study area are endemic to Kerala and 27 species endemic to the Indo-Sri Lankan region. Biogeographical analysis revealed that the araneofauna of central Kerala bears affinities mainly to the Oriental and Palearctic regions, as well as to the fauna of Sri Lanka. Analysis of the faunal composition revealed that the family Araneidae was the taxonomically dominant family in the forest, rice and vegetable ecosystems, whereas in the coconut ecosystem, the family Salticidae (jumping spiders) was the dominant family in terms of species diversity.

INTRODUCTION
Spiders (Arachnida: Araneae) are an integral part of biodiversity since they play many important roles in ecosystems as predators and sources of food for other creatures. They have clearly established themselves as model organisms in biochemical (silk proteins and venom), behavioural (sexual and web-building behaviours) and ecological (foraging, predator-prey systems and integrated pest management) research. Spiders are also utilized by ecologists in the form of conservation tools as ecological indicators of overall biodiversity in many terrestrial communities (Noss 1990). Spiders are extremely sensitive to small changes in habitat structure, including vegetation complexity, litter depth and microclimatic characteristics (Uetz 1991).

Currently 42,751 species of spider in 3859 genera and 110 families have been described validly (Platnick 2012). The estimated total number of spider species in the world can only be guessed at. Coddington and Levi (1991) commented that up to 170,000 species could exist. Platnick explains that if 170,000 species exist, 638 years will pass before the job is finished at the present rate of description.

Regardless of the fact that they form one of the most diverse groups of organisms, and that they have multifaceted ecological functions, spiders have largely been ignored by the conservation community and taxonomists alike because of the human tendency to favour some organisms over others of equal importance because they lack universal appeal (Humphries *et al*. 1995). Many people have a profound dislike for spiders and will not miss an occasion to kill them. This may be due to fear and a dislike of their appearance, behaviour and the venomous nature of a few species. Most likely it is due to a combination of these factors.

Hundreds of spider species are described every year, but the status taxonomic knowledge about spiders is far from adequate. No comprehensive key to modern world families exists, and only about 20% of the families have been revised using modern methods. The scenario is even more dismal in India, with only meagre baseline information existing on the taxonomy and bioecology of spiders in this tropical country, which is considered as one of the 12 mega-biodiversity countries in the world, with about 125,000 described species of living organism and about 400,000 as yet undescribed species (Nagendra & Gadgil 1998). Kerala, one of the small states, lying in the southernmost part of India, is blessed with a rich flora and fauna owing to the presence of the Western Ghats, one of the biodiversity hotspots of the world, in the state. With respect to its geographical, climatic and ecological features, the central Kerala region harbours a rich variety of arachnids, of which spiders have a huge share. This area is also endowed with an extensive forest area and therefore possesses various assemblages of spiders. However, it is saddening to observe that no systematic work has been carried out till date on the systematics, diversity and bioecology of the spiders of this region.

Against this backdrop, a study was carried out with the prime objective of documenting and analysing the spider fauna in the central region of Kerala state, consisting of four districts*, viz,* Ernakulam, Idukki, Trichur and Palghat districts.

MATERIALS AND METHODS

STUDY AREA

The study area consisted of Ernakulam, Idukki, Trichur and Palghat districts in central Kerala, India. The altitude in these districts ranges from the seaboard to 2695 m above MSL. The forest ecosystems selected for the study were Periyar Tiger Reserve, Idukki Wildlife Sanctuary, Eravikulam National Park and Chinnar Wildlife Sanctuary. The agricultural ecosystems selected included rice (*Oryza sativa L.*), coconut (*Cocos nucifera* L.) and vegetables including bitter gourd (*Momordica charantia* L.), snake gourd (*Trichosanthes cucumerina* L.), ivy gourd (*Coccinia grandis* (L.) Voigt), cowpea (*Vigna unguiculata* L. Walp.) and cabbage (*Brassica oleracea* L. var. capitata).

SAMPLING

In the rice and vegetable ecosystems, the study was conducted over a period of 3 years. In rice, sampling was done in the selected sites in six cropping seasons (two crops in a year), whereas in the vegetable crops, sampling was carried out in three cropping seasons (one crop per year). In the coconut and forest ecosystems, fortnightly sampling was conducted over a period of 2 years.

The Quadrat Method: In the rice and vegetable ecosystems, samplings were done fortnightly to study the species composition, diversity and abundance of the spider fauna. Spiders were collected from quadrats (1 m × 1 m). Four quadrats were placed at the four corners of a 10 m × 10 m area. A sufficient core area was left to avoid the edge effect. The hand-picking method was used to collect the spiders from the leaf blades, flowers and dry leaves and from the ground stratum. The area around each plant was searched for possible webs, and the plants were thoroughly examined from the bottom to the top for spiders and pests. Leaves and flowers were also examined. All four quadrats were searched for a total of 1 hour. Spiders were collected by being led into glass tubes (5.2 cm × 2 cm) from the ground stratum and from the tips of plants by beating them with a rod. The falling spiders were collected in glass tubes. Specimens collected were preserved in 70% ethyl alcohol with proper labelling of the locality, date and crop stage and other notes of importance.

The Transect Method: The random transect method using the technique adopted by Aiken and Coyle (2000) was used for spider sampling in forests and coconut plantations. This technique involved a combination of four collection methods to assess the diversity of the spider fauna, namely, ground hand collection, aerial hand collection, beating and sweeping. Time was used as a measure of the sampling effort to make the methods comparable. One sample unit equalled 1 hour of uninterrupted time, during which all spiders encountered were collected (Sebastian et al. 2005). Ground collection involved searching mostly on hands and knees, exploring the leaf litter, logs, rocks and plant surfaces below knee level. Aerial sampling involved searching leaves, branches, tree trunks and the spaces in between, from knee height up to the maximum overhead arm's reach. Beating consisted of striking the vegetation with a 1 m long stick or shaking the vegetation with the hands and catching the falling spiders on an inverted umbrella held below the vegetation. They were later transferred to a fixative. The sweeping method was mainly employed in grasslands. The collected specimens were preserved in 75% alcohol in separate (flat bottomed) tubes with labels containing information regarding the collection.

IDENTIFICATION

The collected spiders were identified with the help of the literature (Tikader 1987; Barrion & Litsinger 1995; Dippenaar-Schoeman & Jocque 1997; Deeleman-Reinhold 2000) using stereoscopic microscopes (Leica MS5, Olympus SZ112). Adult males and females collected from the field were identified up to the species level, whereas immature spiders were identified up to the generic level.

RESULTS

A total of 169 species of spiders belonging to 82 genera and 24 families were sampled from various ecosystems in central Kerala (Table 1). A checklist of the collected spiders is provided in Table 2. In the forest ecosystems, spiders belonging to 118 species, 68 genera and 23 families were sampled (Table 3). The taxonomically dominant family was the family Araneidae, with 27 species of 13 genera. The family Salticidae was represented by 16 species belonging to 13 genera.

In rice, sampling across six cropping seasons yielded individuals belonging to 117 species, 60 genera and 19 families (Table 4). At the generic level, the family Salticidae was the taxonomically dominant family, with a total of 15 genera and 20 species. However, at the species level, the family Araneidae was dominant, with 29 species belonging to 12 genera. Other taxonomically important families were the families Tetragnathidae (18 species belonging to 6 genera), Lycosidae (10 species belonging to 3 genera and Theridiidae (9 species of 7 genera).

In coconut, spiders belonging to 55 species, 38 genera and 14 families were sampled from the four study sites in Ernakulam district of central Kerala during the study (Table 5). The taxonomically dominant family was the family Salticidae, with a total of 17 species belonging to 13 genera recorded during the investigation. The families Araneidae and Lycosidae were represented by 8 species of 5 genera and 8 species of 3 genera, respectively. Monotypic families included the families Clubionidae, Corinnidae, Gnaphosidae, Hersilidae, Miturgidae and Pisauridae.

Individuals belonging to 66 species, 41 genera and 14 families were sampled from bitter gourd crop (Table 6). The family Araneidae was found to be taxonomically dominant, with 19 species of spider belonging to 10 genera. The family Salticidae was represented by 9 species belonging to 8 genera, the family Theridiidae by 8 species of 6 genera and the family Tetragnathidae by 8 species of 3 genera.

In snake gourd, sampling yielded spider species belonging to 41 species, 29 genera and 11 families (Table 7). The family Aranediae was the taxonomically dominant family, with 13 species of 8 genera. The family Salticidae was represented by 7 species of 7 genera. The other taxonomically important families were the families Lycosidae (6 species of 3 genera) and Tetragnathidae (4 species belonging to 2 genera).

In ivy gourd, spiders belonging to 33 species, 23 genera and 10 families were sampled (Table 8). The family Araneidae was the taxonomically dominant family, comprising 13 species of 8 genera. The family Salticidae was represented by 6 species belonging to 6 genera. In cowpea, sampling yielded individuals belonging to 33 species, 23 genera and 8 families (Table 9). Family-level analysis reveals that the family Aranediae was the taxonomically dominant family, with 13 species belonging to 8 genera recorded. The family Salticidae was represented by 5 species of 5 genera, whereas the family Lycosidae was also represented by 5 species of 3 genera. In cabbage, spiders belonging to 21 species, 15 genera and 6 families were sampled (Table 10). The family Araneidae was the taxonomically dominant family, with 8 species belonging to 6 genera. The family Salticidae was represented by 4 species belonging to 4 genera, and the family Tetragnathidae was represented by 4 species of 2 genera.

DISCUSSION

Efforts at inventorying the araneofauna in the various ecosystems of central Kerala resulted in the documentation of 169 species of spider belonging to 82 genera and 24 families (Tables 1 & 2). This study, covering four districts in central Kerala, revealed that the spider fauna in the study area is very rich both qualitatively and quantitatively. The 24 spider families recorded from central Kerala represent 40% of the total number of families reported from the country (Platnick 2012). Thirty-five species were unique to the forest ecosystems, whereas 49 species were unique to the agricultural ecosystems. Eighty-five species were shared by both the ecosystems (Table 2). Among the spiders sampled, five species turned out to be newly discovered, viz. *Acusilas* sp. nov. (Araneidae), *Gea* sp. nov. (Araneidae), *Ctenus* sp. nov. (Ctenidae), *Linyphia* sp. nov. (Linyphiidae) and *Achaearanea* sp. nov. (Theridiidae).

The number of species reported from central Kerala is higher than the number recorded from many other regions surveyed in India. For instance, Sugumaran et al. (2005) studied the spider fauna in different forest ecosystems in the Western Ghats of Tamil Nadu and reported 56 species of spider belonging to 18 families. Sivaperuman and Rathore (2004) recorded 28 species of spider belonging to 13 families and 21 genera from Desert National Park in Rajasthan. The species richness is very high when compared with some other regions such as Sikkim (55 species (Tikader 1970)) and the Andaman and Nicobar Islands (65 species (Tikader 1977)). The present investigation is comparable with a study by Siliwal *et al.* (2003), who recorded 116 species belonging to 66 genera and 25 families from Purna Wildlife Sanctuary, Dangs, Gujarat. Hore and Uniyal (2008) studied the diversity and composition of spider assemblages in five vegetation types of the Terai Conservation Area between the Himalayan foothills and the Gangetic plains and sampled 3666 adult spiders representing 22 families, 60 genera, and 160 species. From these results, it can be summarized that the spider fauna of central Kerala is more rich and diverse compared with any other region in India. Because of the complex interaction of various climatic factors such as the high rainfall and humidity with diverse topographical features, central Kerala possesses many smaller but diverse environmental niches that can support a diverse spider fauna.

The discovery of new species, as well as the sighting of a number of species and genera for the first time from India, indicates the biological wealth of this region and further points out the necessity for more detailed exploration in order to comprehensively understand the biodiversity of our country. The discovery of any new species is significant considering the fact that biodiversity is disappearing from our planet at an astonishing rate. Accurately naming new species and subspecies helps create a more meaningful map of biodiversity distribution. It is also a necessary prerequisite for achieving legal protection for threatened habitats such as the Western Ghats.

ENDEMISM

A total of five species recorded from the study area are endemic to Kerala. These are *Gasteracantha geminata* (family Araneidae); *Ctenus indicus* (family Ctendiae); *Fecenia travancoria* and *Psechrus torvus* (family Psechridae); and *Tetragnatha cochinensis* (family Tetragnathidae). Further, 27 species reported from central Kerala are endemic to the Indo-Sri Lankan region. These are *Uloborus danolius, Uloborus krishnae* (family Uloboridae); *Achaearanea durgae, Argyrodes andamanensis, Argyrodes gazedes* and *Theridula angula* (family Theridiidae); *Linyphia urbasae* (family Lyniphiidae); *Leucauge dorsotuberculata, Leucauge pondae, Tetragnatha andamanensis, Tetragnatha cochinensis* and *Tetragnatha viridorufa* (family Tetragnathidae); *Arachnura angura, Cyclosa hexatuberculata, Neoscona bengalensis* and *Neoscona mukerjei* (family Araneidae); *Lycosa poonaensis* and *Lycosa tista* (family Lycosidae); *Pisaura gitae* (family Pisauridae); *Oxyopes ashae* and *Oxyopes rukminiae* (family Oxyopidae); *Ctenus cochinensis* and *Ctenus indicus* (family Ctenidae); *Heteropoda nilgirina* (family Sparassidae); and *Thomisus andamanensis, Thomisus lobosus* and *Thomisus projectus* (family Thomisidae).

It is apparent that many species found in central Kerala have not been reported from any other regions in India. This phenomenon can be explained by the relative isolation of the study area provided by the Western Ghats in the east and the Arabian Sea in the west (Nagendra & Gadgil 1998). Thus, the existing data suggest that central Kerala represents one of the main centres of speciation in Asia.

Endemism may arise by several mechanisms, but underlying them all is the principle of geographical isolation. Conserving biological wealth requires action in both areas rich in endemic species and areas of high biological diversity. The uniqueness of species compositions, as indicated by the levels of endemism and habitat specialization, is more important in establishing regional conservation priorities (Platnick 1991). Threatened centres of endemism are major biodiversity hotspots (Roberts et al. 2002), and conservation efforts targeted toward them could help avert the loss of biodiversity. The present investigation could serve as a baseline for future studies on the spiders of Kerala, especially the Western Ghats. These future investigations can be conducted as a continuation of the present investigation by utilizing additional collecting methods and/or sampling all available habitats, thereby inventorying poorly documented spider taxa and perhaps discovering new species along the way.

AFFINITIES

The araneofauna of central Kerala displays affinities mainly to the Oriental and Palearctic regions, as well as to the fauna of Sri Lanka. Species such as *Stegodyphus sarasinorum* (family Eresidae); *Zosis geniculata* (family Uloboridae); *Achaearanea mundula, Argyrodes flavescens, Ariamnes flagellum, Chryssoargyrodiformis, Phycosoma martinae* (family Theridiidae); *Neriene sundaica* (family Linyphiidae); *Herennia multipuncta, Nephila kuhlii, Nephila pilipes* (family Nephilidae); *Dyschiriognatha dentata, Leucauge celebesiana, L. tessellata, Opadometa fastigatata, Tetragnatha ceylonica, Tetragnatha andamanensis* and *Tyloridae culta* (family Tetragnathidae); *Araneus ellipticus, Argiope aemula, Argiope. anasuja, Argiope catenulata, Argiope pulchella, Cyclosa bifida, Cyclosa confraga, Cyclosa insulana, Cyrtophora cicatrosa, Cyrtophora moluccensis, Eriovixia laglaizei, Gasteracantha geminata, Gasteracantha haselltii, Gasteracantha kuhli, Neoscona molemensis, Neoscona vigilans, Neoscona nautica* and *Parawixia dehaani* (family Araneidae); *Hippasa agelenoides, Hippasa greenalliae, Pardosa pseudoannulata, Pardosa sumatrana* (family Lycosidae); *Thalassius albocinctus* (family Pisauridae); *Oxyopes birmanicus, Oxyopes. javanus* and *Peucetia viridana* (family Oxyopidae); *Fecenia travancoria* and *Psechrus torvus* (family Psechridae); *Cheiracanthium melanostomum* (family Miturgidae); *Clubiona drassodes* (family Clubionidae); *Castianeira zetes* (family Corinnidae); *Heteropoda venatoria* (family Sparassidae); *Camaricus formosus* (family Thomisidae); *Carrhotus viduus, Menemerus bivittatus, Myrmarachne orientates, Phintella vittata, Plexippus paykulli, Plexippus petersi, Portia fimbriata, Rhene flavigera, Siler semiglaucus, Telamonia dimidiata* and *Thiania bhamoensis* (family Salticidae) have Oriental affinities.

The affinities shown by the araneofauna to the Oriental region are not surprising since the general hypothesis is that the Indian biota is formed as a result of displacement by invaders from other regions of the Oriental region after its separation from Gondwanaland and merger with Asia (Holloway 1974).

Species such as *Leucauge decorata, Leucauge subgemmea, Tetragnatha ceylonica* and *Tetragnatha javana* (family Tetragnathidae); *Nephila pilipes* (family Nephilidae); *Eriophora himalayaensis, Chorizopes bengalensis, Eriovixia laglaizei, Gasteracantha hasseltti* and *Gibbaranea bituberculata* (family Araneidae); *Argyrodes flavescens* (family Theridiidae); *Hippasa greenalliae* and *Hippasa lycosina* (family Lycosidae); *Oxyopes birmanicus* and *Oxyopes shweta* (family Oxyopidae); *Clubiona drassodes* (family Clubionidae); and *Myrmarachne plataleoides* (family Salticidae) have Paleartic affinities.

Species such as *Argiope anasuja, Argiope aemula, Argiope catenulata, Neoscona vigilans, Cyclosa confraga, Cyclosa insulana, Eriovixia laglaizei, Gasteracantha geminata, Gasteracantha remifera, Parawixia dehanii* and *Cyrtophora moluccensis* (family Araneidae); *Stegodyphyus sarasinorum* (family Eresidae); *Herennia multipuncta, Nephila pilipes* and *Nephilengys malabarensis* (family Nephilidae); *Tylorida culta, Opadometa fastigata* and *Tetragnatha ceylonica,* (family Tetragnathidae); *Hersilia savigyni* (family Hersilidae); *Argyrodes flavescens* (family Theridiidae); *Heteropoda venetoria* and *Olios milleti* (family Sparassidae); *Oxyopes hindostanicus* and *Peucetia viridana* (Family Oxyopidae); *Artema Atlanta* (Family Pholcidae); *Hippasa greenalliae* (family Lycosidae);and *Hyllus semicupreus* and *Myrmarachne plataleoides* (family Salticidae) bear affinities to the island fauna of Sri Lanka.

Analysing the relationships between the Western Ghats (southern India) and Sri Lanka using multiple vertebrate and invertebrate groups, Bossuyt *et al.* (2004) inferred that the Sri Lankan fauna was derived from mainland India. The present investigation confirms this hypothesis, as evidenced by the remarkable similarities existing between the spider faunas of central Kerala (Western Ghats) and Sri Lanka.

FAUNAL COMPOSITION

An analysis of the faunal composition of spiders in forest and agricultural ecosystems in central Kerala revealed that the family Araneidae was the taxonomically dominant family in forest, rice and vegetable ecosystems, whereas in coconut, the family Salticidae (jumping spiders) turned out to be the dominant family in terms of species diversity.

The family Araneidae is the largest family of spiders. Members of this family construct orb-webs (wheel-shaped two-dimensional webs) and are often found in gardens, fields and forests. The dominance of this family in the study area is a direct consequence of the vegetational architecture. The vegetational architecture plays a major role in the species composition found within a habitat (Scheidler 1990), and vegetation that is structurally more complex can sustain a higher abundance and diversity of spiders (Hatley & MacMahon 1980). It is apparent that tropical forests possess a congenial environment for the construction of orb webs. In a study conducted in Costa Rica, Greenstone (1984) found that vegetation structure but not prey availability significantly determined the diversity of web spiders. Since the abundance of orb-weavers is influenced by the physical structure of the vegetation and the availability of sites for webs (Greenstone 1984; Wise 1993), the undisturbed bushes and sparse ground-layer vegetation in primary forests might be able to support a larger population of orb-weaving spiders that require larger spaces for web construction. This also holds true for the various vegetable crops studied, which provide the necessary substrata at different vertical strata for the construction and anchoring of orb-webs and thereby favour the survival of araneids over members of other spider families.

Even though the availability of substrates for anchoring webs in rice fields is limited compared with other terrestrial habitats, araneids dominated the rice fields of central Kerala in terms of species diversity. This result is in conformity with the findings of Bambaradeniya and Edirisinghe (2001) in the rice fields of Sri Lanka. It can be inferred that even simple vegetational structures such as rice plants can provide ample opportunities for the construction and maintenance of webs at different strata for successful prey capture. Web-building species are stationary predators that wait for food to come to them. Most web weavers depend largely on relatively few prey groups that are available in high numbers in a particular environment. The rice agroecosystem provides a continuous supply of prey species, namely insects, in great numbers at all seasons of crop growth, and this explains the probable dominance of araneids, the most diverse web weavers among spiders, in this ecosystem.

The dominance of the family Salticidae in coconut is a consequence of the unique vegetational architecture of this crop. Due to the perennial nature of the crop, web-anchoring substrata are practically unavailable in coconut gardens. Routine weeding and other cultural practices further eliminate herbs and shrubs that provide ideal habitats for the survival of web weavers such as araneids and tetragnathids. This condition favours the survival of free living spiders such as salticids (jumping spiders), which do not construct webs for prey capture but rather use their eyesight and agility to hunt prey. Salticids can often be observed on the barks of coconut palms, actively moving in pursuit of the prey, whereas the leaf folds of the coconut palm provide perfect sites for construction of retreats where the females can protect their eggs, and these retreats also serve as shelters when the spiders are moulting.

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Table 1.

Total numbers of families, genera and species of spider recorded from forest and agricultural ecosystems (combined) in central Kerala, India

Sl. No.	Family	Genera	Species
1	Araneidae	15	42
2	Clubionidae	1	2
3	Corinnidae	1	1
4	Ctenidae	1	2
5	Eresidae	1	1
6	Filistatidae	1	1
7	Gnaphosidae	1	1
8	Hersillidae	1	1
9	Lyniphidae	2	4
10	Lycosidae	3	13
11	Miturgidae	1	1
12	Nephilidae	3	4
13	Oxyopidae	2	13
14	Philodromidae	2	2
15	Pholcidae	1	1
16	Pisauridae	2	3
17	Psechridae	2	2
18	Salticidae	18	25
19	Scytodidae	1	1
20	Sparassidae	2	3
21	Tetragnathidae	6	20
22	Theridiidae	8	14
23	Thomisidae	4	7
24	Uloboridae	3	5
	Total	82	169

Table 2. Checklist of spiders recorded from forest and agricultural ecosystems in central Kerala, India

Sl. No.	Taxon	Distribution		
		Forest ecosystem	Agricultural ecosystems	Shared
	I. Family Araneidae Simon, 1895			
1	*Acusilas* sp. nov.*			x
2	*Arachnura angura* Tikader, 1970	x		
3	*Araneus bilunifer* Pocock, 1900			x
4	*A. ellipticus* (Tikader & Bal, 1981)			x
5	*Araneus* sp.			x
6	*Argiope aemula* (Walckenaer, 1842)			x
7	*A. anasuja* Thorell, 1887			x
8	*A. catenulata* (Doleschall, 1859)		x	
9	*A. pulchella* Thorell, 1881			x
10	*Argiope* sp.			x
11	*Chorizopes bengalensis* Tikader, 1975			x
12	*Cyclosa bifida* (Doleschall, 1859)			x
13	*C. confraga* (Thorell, 1892)			x
14	*C. hexatuberculata* Tikader, 1982	x		
15	*C. insulana* (Costa, 1834)	x		
16	*C. mulmeinensis* (Thorell, 1887)		x	
17	*Cyclosa* sp.			x
18	*Cyrtarachne* sp.			x
19	*Cyrtophora cicatrosa* (Stoliczka, 1869)			x
20	*C. citricola* (Forskål 1775)			x
21	*C. feai* (Thorell, 1887)		x	
22	*C. moluccensis* (Doleschall, 1857)	x		
23	*Cyrtophora* sp.		x	
24	*Eriophora himalayaensis* Tikader, 1975	x		
25	*Eriovixia excelsa* (Simon, 1889)			x
26	*E. laglaizei* (Simon, 1877)			x
27	*E. poonaensis* (Tikader & Bal, 1981)			x
28	*Eriovixia* sp.		x	
29	*Gasteracantha dalyi* Pocock, 1900	x		
30	*G. geminata* (Fabricius, 1798)			x
31	*G. kuhli* C.L. Koch, 1837	x		
32	*Gea* sp. nov.		x	
33	*Gibbaranea bituberculata* (Walckenaer, 1802)		x	
34	*Neoscona bengalensis* Tikader & Bal, 1981			x
35	*N. molemensis* Tikader & Bal 1981		x	
36	*N. mukerjei* Tikader, 1980			x
37	*N. nautica* (L. Koch, 1875)		x	
38	*N. pavida* (Simon, 1906)		x	
39	*N. theisi* (Walckenaer, 1842)		x	

40	*N. vigilans* (Blackwall, 1865)			x
41	*Neoscona* sp.	x		
42	*Parawixia dehaani* (Doleschall, 1859)	x		
	II. Family Clubionidae Wagner, 1887			
43	*Clubiona drassodes* O.P. Cambridge, 1874			x
44	*Clubiona* sp.			x
	III. Family Corinnidae arsch, 1880			
45	*Castianeira zetes* Simon, 1897			x
	IV. Family Ctenidae, Keyserling, 1877			
46	*Ctenus indicus* Gravely, 1931	x		
47	*Ctenus idukkiyensis* sp. nov.			x
	V. Family Eresidae C.L. Koch, 1851			
48	*Stegodyphus sarasinorum* Karsch, 1891			x
	VI. Family Filistatidae Ausserer, 1867			
49	*Pritha* sp.		x	
	VII. Family Gnaphosidae Pocock, 1898			
50	*Gnaphosa* sp.			x
	VIII. Family Hersilidae Thorell, 1870			
51	*Hersilia savignyi* Lucas, 1836	x		
	IX. Family Lyniphidae Blackwall, 1859			
52	*Linyphia* sp. nov.	x		
53	*L. urbasae*Tikader, 1970			x
54	*Linyphia* sp.		x	
55	*Neriene sundaica* (Simon, 1905)**	x		
	X. Family Lycosidae Sundevall, 1833			
56	*Hippasa agelenoides* (Simon, 1884)			x
57	*H. greenalliae* (Blackwall, 1867)	x		
58	*H. holmerae* Thorell, 1895		x	
59	*H. lycosina* Pocock, 1900	x		
60	*Hippasa* sp.		x	
61	*Lycosa poonaensis* Tikader & Malhotra, 1980		x	
62	*L. tista* Tikader, 1970			x
63	*Lycosa* sp.			x
64	*Pardosa amkhasensis* Tikader & Malhotra, 1976		x	
65	*P. minuta* Tikader & Malhotra, 1976			x
66	*P. pseudoannulata* (Bösenberg & Strand, 1906)			x
67	*P. sumatrana* (Thorell 1890)			x
68	*Pardosa* sp.			x
	XI. Family Miturgidae Simon, 1885			
69	*Cheiracanthium melanostomum* (Thorell, 1895)			x
	XII. Family Nephilidae Simon, 1894			
70	*Herennia multipuncta* (Doleschall, 1859)	x		

71	*Nephila kuhlii* Doleschall, 1859	x		
72	*N. pilipes* (Fabricius, 1793)			x
73	*Nephilengys malabarensis* (Walckenaer, 1842)	x		
	XIII. Family Oxyopidae Thorell, 1870			
74	*Oxyopes ashae* Gajbe, 1999		x	
75	*O. bharatae* Gajbe 1999		x	
76	*O. birmanicus* Thorell, 1887		x	
77	*O. hindostanicus* Pocock, 1901			x
78	*O. javanus* Thorell, 1887			x
79	*O. lineatipes* (C. L. Koch, 1847)**	x		
80	*O. ratnae* Tikader, 1970			x
81	*O. sakuntalae* Tikader, 1970		x	
82	*O. shweta* Tikader, 1970			x
83	*O. sunandae* Tikader, 1970			x
84	*Oxyopes* sp.			x
85	*Peceutia* sp.	x		
86	*Peucetia viridana* (Stoliczka, 1869)			x
	XIV. Family Philodromidae Thorell, 1870			
87	*Philodroumus* sp.	x		
88	*Tibellus elongatus* Tikader, 1960	x		
	XV. Family Pholcidae C.L. Koch, 1851			
89	*Artema atlanta* Walckenaer, 1837		X	
	XVI. Family Pisauridae Simon, 1890			
90	*Pisaura gitae* Tikader, 1970			x
91	*Pisaura* sp.		x	
92	*Thalassius albocinctus* (Doleschall, 1859)			x
	XVII. Family Psechridae Simon, 1890			
93	*Fecenia travancoria* Pocock, 1899	x		
94	*Psechrus torvus* (O.P.Cambridge, 1869)	x		
	XVIII. Family Salticidae Blackwall, 1841			
95	*Bavia* sp.			x
96	*Bianor incitatus* Thorell, 1890			x
97	*Carrhotus viduus* (C.L. Koch, 1846)		x	
98	*Cyrba ocellata* (Kroneberg, 1875)		x	
99	*Epeus indicus* Proszynski, 1992		x	
100	*Hasarius adansoni* (Audouin, 1826)			x
101	*Hindumanes karnatakaensis* (Tikader & Biswas, 1978)		x	
102	*Hyllus diardi* (Walckenaer, 1837)**			x
103	*H. semicupreus* (Simon, 1885)		x	
104	*Myrmarachne orientales* Tikader, 1973			x
105	*M. plataleoides* (O.P. Cambridge, 1869)			x
106	*Phaeacius* sp.			x
107	*Phintella vittata* (C.L. Koch, 1846)			x

108	*Phintella* sp.		x	
109	*Plexippus paykulli* (Audouin, 1826)			x
110	*P. petersi* (Karsch, 1878)			x
111	*Plexippus* sp.		x	
112	*Portia fimbriata* (Doleschall, 1859) **			x
113	*Rhene danieli* Tikader, 1973		x	
114	*R. flavigera* (C. L. Koch, 1846)			x
115	*Siler semiglaucus* Simon, 1901**			x
116	*Telamonia dimidiata* (Simon, 1899)			x
117	*Telamonia* sp.			x
118	*Thiania bhamoensis* Thorell,1887			x
119	*Thyene* sp.		x	
	XIX. Family Scytodidae Blackwall, 1864			
120	*Scytodes fusca* Walckenaer, 1837	x		
	XX. Family Sparassidae Bertkau, 1872			
121	*Heteropoda nilgirina* Pocock, 1901	x		
122	*H. venatoria* (Linnaeus, 1767)			x
123	*Olios milleti* (Pocock, 1901)			x
	XXI. Family Tetragnathidae Menge, 1866			
124	*Dyschiriognatha dentata* Zhu & Wen, 1978**		x	
125	*Leucauge celebesiana* (Walckenaer, 1842)			x
126	*L. decorata* (Blackwall 1864)			x
127	*L. dorsotuberculata* Tikader, 1982	x		
128	*L. pondae* Tikader, 1970			x
129	*L. subgemmea* Bösenberg & Strand, 1906**		x	
130	*L. tessellata* (Thorell, 1887)			x
131	*Leucauge* sp.			x
132	*Opadometa fastigata* (Simon, 1877)			x
133	*Orsinome* sp.		x	
134	*Tetragnatha andamanensis* Tikader, 1977		x	
135	*T. ceylonica* O. P. Cambridge, 1869			x
136	*T. cochinensis* Gravely, 1921		x	
137	*T. javana* (Thorell, 1890)		x	
138	*T. mandibulata* Walckenaer, 1842			x
139	*T. maxillosa* Thorell, 1895			x
140	*Tetragnatha vermiformis* Emerton, 1884			x
141	*T. viridorufa* Gravely, 1921		x	
142	*Tetragnatha* sp.			x
143	*Tylorida culta* (O. P. Cambridge, 1869)		x	
	XXII. Family Theridiidae Sundevall, 1833			
144	*Achaearanea* sp. nov.			x
145	*A. durgae* Tikader, 1970		x	
146	*A. mundula* (L. Koch, 1872)	x		
147	*Achaearanea* sp.	x		
148	*Ariamnes flagellum* (Doleschall, 1857)			x

149	*Argyrodes flavescens* (Cambridge, 1880)**	x		
150	*A. gazedes* Tikader, 1970	x		
151	*Argyrodes* sp.		x	
152	*Chrysso argyrodiformis* (Yaginuma, 1952)			x
153	*Coleosoma* sp. **		x	
154	*Phycosoma martinae* (Roberts, 1983)		x	
155	*Phycosoma* sp.		x	
156	*Theridion* sp.			x
157	*Theridula angula* Tikader, 1970			x
	XXIII. Family Thomisidae Sundevall, 1833			
158	*Camaricus formosus* Thorell, 1887	x		
159	*Misumena* sp.		x	
160	*Thomisus andamanensis* Tikader, 1980			x
161	*T. lobosus* Tikader, 1965			x
162	*T. projectus* Tikader, 1960	x		
163	*Thomisus* sp.		x	
164	*Xysticus* sp.	x		
	XXIV. Family Uloboridae Thorell, 1869			
165	*Miagrammopes* sp.	x		
166	*Uloborus danolius* Tikader, 1969			x
167	*U. krishnae* Tikader, 1970			x
168	*Uloborus* sp.		x	
169	*Zosis geniculata* (Olivier, 1789)			x
Total		35	48	85

**First report of the genus from India*

*** First report of the species from India*

Table 3.

Total numbers of families, genera and species of spider recorded from the forest ecosystems in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	13	27
2	Clubionidae	1	2
3	Corinnidae	1	1
4	Ctenidae	1	2
5	Eresidae	1	1
6	Gnaphosidae	1	1
7	Hersillidae	1	1
8	Lyniphidae	2	3
9	Lycosidae	3	9
10	Miturgidae	1	1

11	Nephilidae	3	4
12	Oxyopidae	2	9
13	Philodromidae	2	2
14	Pholcidae	1	1
15	Pisauridae	2	2
16	Psechridae	2	2
17	Salticidae	13	16
18	Scytodidae	1	1
19	Sparassidae	2	3
20	Tetragnathidae	3	12
21	Theridiidae	6	9
22	Thomisidae	3	5
23	Uloboridae	3	4
Total		68	118

Table 4.

Total numbers of families, genera and species of spider recorded from the rice (*Oryza sativa* L.) agroecosystem in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	12	29
2	Clubionidae	1	2
3	Corinnidae	1	1
4	Ctenidae	1	1
5	Eresidae	1	1
6	Filistatidae	1	1
7	Gnaphosidae	1	1
8	Hersillidae	1	1
9	Lyniphidae	1	1
10	Lycosidae	3	10
11	Miturgidae	1	1
12	Oxyopidae	2	11
13	Pisauridae	2	3
14	Salticidae	15	20
15	Sparassidae	1	1
16	Tetragnathidae	6	18
17	Theridiidae	7	9
18	Thomisidae	2	4
19	Uloboridae	1	2
Total		60	117

Table 5.

Total numbers of families, genera and species of spider recorded from the coconut (*Cocos nucifera L.*) agroecosystem in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	5	8
2	Clubionidae	1	1
3	Corinnidae	1	1
4	Gnaphosiae	1	1
5	Hersillidae	1	1
6	Lycosidae	3	8
7	Miturgidae	1	1
8	Oxyopidae	1	3
9	Pisauridae	1	1
10	Salticidae	13	17
11	Sparassidae	2	2
12	Tetragnathidae	1	4
13	Therididae	5	5
14	Uloboridae	2	2
Total		38	55

Table 6.

Total number of families, genera and species of spider recorded from bitter gourd (*Momordica charantia L.*) crop in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	10	19
2	Clubionidae	1	1
3	Hersillidae	1	1
4	Lyniphidae	1	1
5	Lycosidae	3	7
6	Miturgidae	1	1
7	Nephilidae	1	1
8	Oxyopidae	1	4
9	Pisauridae	1	1
10	Salticidae	8	9
11	Tetragnathidae	3	8
12	Theridiidae	6	8
13	Thomisidae	2	2
14	Uloboridae	2	3
Total		41	66

Table 7.

Total numbers of families, genera and species of spider recorded from snake gourd (*Trichosanthes cucumerina L.*) crop in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	8	13
2	Clubionidae	1	1
3	Lycosidae	3	6
4	Miturgidae	1	1
5	Oxyopidae	1	3
6	Pisauridae	1	1
7	Salticidae	7	7
8	Tetragnathidae	2	4
9	Theridiidae	3	3
10	Thomisidae	1	1
11	Uloboridae	1	1
Total		29	41

Table 8.

Total numbers of families, genera and species of spider recorded from ivy gourd (*Coccinia grandis L.*) Voigt) crop in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	8	13
2	Lycosidae	2	3
3	Nephilidae	1	1
4	Oxyopidae	1	3
5	Salticidae	6	6
6	Sparassidae	1	1
7	Tetragnathidae	1	3
8	Theridiidae	1	1
9	Thomisidae	1	1
10	Uloboridae	1	1
Total		23	33

Table 9.

Total numbers of families, genera and species of spider recorded from cowpea (*Vigna unguiculata* L. Walp.) crop in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	8	13
2	Lycosidae	3	5
3	Miturgidae	1	1
4	Oxyopidae	1	3
5	Salticidae	5	5
6	Tetragnathidae	2	3
7	Theridiidae	2	2
8	Thomisidae	1	1
Total		23	33

Table 10.

Total numbers of families, genera and species of spider recorded from cabbage (*Brassica oleracea* L. var. capitata) crop in central Kerala, India

Sl. No.	Family	No. of Genera	No. of Species
1	Araneidae	6	8
2	Lycosidae	1	2
3	Oxyopidae	1	2
4	Salticidae	4	4
5	Tetragnathidae	2	4
6	Uloboridae	1	1
Total		15	21

MYGALOMORPHS OF INDIA: AN OVERVIEW

Manju Siliwal[1], **Sanjay Molur**[1] **and Robert Raven**[2]
1. Zoo Outreach Organisation, Wildlife Information Liaison Development Society, 9-A, Lal Bahadur Colony, Peelamedu, Coimbatore 641004, Tamil Nadu, India.
email: manjusiliwal@gmail.com
2. Queensland Museum, Grey Street, PO Box 3300, South Brisbane, 4101, Queensland, Australia

ABSTRACT
The mygalomorph spiders remain poorly studied in India. So far, 89 species under 27 genera and eight families have been reported from the country. Most of the mygalomorph descriptions from the region were done more than a century ago, based on a few prominent morphological characters. In the last 10 years, interest in mygalomorphs has revived, and along with taxonomy, studies on ecology, natural history and conservation of mygalomorphs have been initiated. Nineteen new species have been reported, and 18 taxa have undergone taxonomic revision. Endemism is high at the species level, and the endemic species are threatened with habitat loss, fragmentation and pet trade. Fourteen species of mygalomorph were listed in the IUCN Red List in 2008. Immediate conservation actions are needed to prevent the extinction of threatened tarantulas in the wild.

INTRODUCTION
The spiders (Phylum Arthropoda: Class Arachnida: Order Araneae) are top-level predators amongst the invertebrates and play an important role by keeping a check on insect populations (Marc & Canard, 1997; Marc *et al.*, 1999). Spiders are broadly classified into two suborders and two infraorders, namely Suborder Mesothelae and Suborder Opisthothelae,the latter with the infraorders Mygalomorphae and Araneomorphae. Mesothelae spiders are the most primitive in the evolutionary history of spiders, with a segmented abdomen and four pairs of primitive spinnerets. So far, these spiders have not been reported from India. Infraorder Mygalomorphae also consists of primitive spiders that resemble the Mesothelae spiders in having chelicerae (jaws) that move vertically, two pairs of book lungs,a stout body and stout legs. But unlike Mesothelae spiders, they do not have segmented abdomens, and the number of spinnerets is reduced to one to three pairs. In contrast, the more evolved or modern spiders of Infraorder Araneomorphae have horizontally moving chelicerae, although the primitive families (Gradungulidae, Austrochilidae) belonging to this group have two pairs of booklungs—most have maximally a single pair of book lungs, a relatively small body-size and slender legs.

To date, 43,678 species in 3898 genera and 112 families of spider have been recorded from around the world (Platnick, 2013).The actual number of species is believed to be three to fivetimes higher (Coddington & Levi, 1991). The number of mygalomorph species recorded in the world is 2731 in 328 genera and 16 families.The most diverse and dominant family is the Theraphosidae, represented by 124 genera and 946 species (Platnick, 2013). A very small number of mygalomorphs have been reported from India, a mere 89 species in 27 genera and eight families. Theraphosidae is the most dominant family, represented by 52 species and 12 genera. Theraphosids are relatively easy to locate:they haveburrows with open entrances, compared with the burrows of mygalomorphs of the families Atypidae, Barychelidae, Ctenizidae and Idiopidae, which have trap doors.

RESULTS AND DISCUSSION
TAXONOMY
Studies of Indian mygalomorph spiders were initiated in the late 19th century (Siliwal *et al.*, 2005) with the description of new species based on specimens deposited in various European museums. The first mygalomorph described from India was *Chilobrachys stridulans* (Wood Mason, 1877)from Sibsagar, Assam. Three arachnologists played a major role in initiating

studies on Indian mygalomorphs: R. I. Pocock, arachnologist at the BritishMuseum of Natural History (=NaturalHistoryMuseum), London; F. H. Gravely, Assistant Superintendent of the Government Museum, Madras; and Eugène Simon, French arachnologist. Pocock and Simon described 37 and eight species, respectively, on the basis of specimens deposited in various European museums (Pocock, 1895, 1899, 1900; Simon, 1888, 1891, 1892, 1897, 1906). The first comprehensive book on spiders of this region was by Pocock (1900), and it had a compilation of spider descriptions (including mygalomorphs) from India, Ceylon (=Sri Lanka) and Burma (=Myanmar). The identification keys provided by Pocock (1900) were very precise and are widely referred to by arachnologists of the region to date (Siliwal *et al*., 2005). Later, Gravely (1915, 1921, 1935a, 1935b) described 15 species of mygalomorph on the basis of collections made during his surveys in various parts of India. He also provided natural history information on mygalomorphs for the first time. Many other arachnologists also described a few species each, again on the basis of Indian specimens deposited in different museums (Walckenaer, 1806; P.-Cambridge, 1883, 1890; Karsch, 1891; Thorell, 1891;Hirst, 1909; Chamberlin, 1917). In the period between 1935 and 2000, work on mygalomorphs was insignificant and dwindling. During this period there were very few, sporadic publications on mygalomorphs from India(Coyle, 1995; Tikader, 1969, 1977; Barman, 1978).

In September 2001, a hands-on training workshop was conducted in Parambikulam Wildlife Sanctuary to create awareness and revive interest in tarantula studies amongst Indian researchers (Molur & Daniel, 2001). Subsequently, researchers started noticing and recording spiders in different parts of India, and a few projects were initiated. As a result of this, one new genus and 19 new species of mygalomorph have been described in the last 10 years (Smith, 2004, 2006; Siliwal *et al.*, 2007; Jose & Sebastian, 2008;Siliwal & Molur, 2009b; Siliwal *et al*., 2009b, 2009c; Mirza *et al.*, 2011;Sanap & Mirza, 2011;Siliwal *et al*., 2011; Mirza & Sanap, 2012; Mirza *et al*., 2012; Siliwal *et al.*, 2012). as Apart from descriptions of new species, many range extension records and taxonomic redescriptions of various species of Indian mygalomorph have been published (Cheeran &Nagaraj, 1997; Molur & Daniel, 2001; Molur *et al*., 2004; Rao *et al*., 2004; Ganeshkumar & Siliwal, 2005; Siliwal & Molur, 2009a).

PROBLEMS IN TAXONOMY OF MYGALOMORPHS OF THE REGION

Nearly 70% of the mygalomorphs described from India were described during the late 19th or early 20th century, a period before independence, mainly on the basis of specimens deposited in various European museums. The descriptions of these species are very basic, based on a few distinct morphological characters that are not of much use in recent comparative taxonomy. After India's independence, 29 new species, a very small number,were described with taxonomic detail. Mygalomorph studies carried out in the past and present have remained limited to a few pockets in the country, mainly to biodiversity-rich areas such as the Western Ghats, Northeast India and parts of eastern India. There are areas such as central and north India that have remained neglected areas as far as mygalomorphs are concerned. This is mainly due to a lack of surveys and funds for taxonomic studies. Further, there have been no further collections of many of the mygalomorphs since their first description, due to which there are a few invalid descriptions and taxonomic confusion.

About 60% of the Indian mygalomorphs are known only from the type locality. Of these spiders,60% were described a century ago. Localities names have changed in many instances over the years. Moreover, there are six species, *Chilobrachys flavopilosus* (Simon, 1884),*Idiops fortis* (Pocock, 1900), *I. fossor* (Pocock, 1900), *Indothele mala* Coyle, 1995,I. *rothi Coyle*, 1995 and *Latouchia cryptica* (Simon, 1897), whose exact type localities are not known. Therefore, it is difficult to obtain fresh specimens of these species from the wild to work on their taxonomy. According to Platnick (2013), *C. flavopilosus* occurs in India and Myanmar, but there is no formal record of this species from India. As this species occurs in Myanmar, it can be inferred that this species could occur in northeastern India, in areas adjoining Myanmar, but so far there have been no reports of this species from Northeast India.

A total of 47 species have been described based on a single sex, of which, 34 are based on female specimens and only 13 are based on male specimens. This difference is mainly because males are found only during the mating season and have a short life span. After maturing, males lead a nomadic life.During the day they occupy temporary hideouts under rocks or wooden logs or in crevices and depressions in roadside bunds. A majority of surveys in protected areas are carried out during the daytime, and so it is very difficult to locate males during these surveys. Males are best caught in pitfall traps but it is not possible to catch them during short surveys.

Many species have undergone taxonomic changes recently. A major contribution to revising the mygalomorphs of the world was made by Raven (1980, 1985). He elevated the Hexathelidae, Idiopidae and Nemesiidae to family status and the genera *Damarchus, Heligmomerus, Idiops* and *Macrothele* were transferred to other families. Recently, a total of nine species have been transferred,seven species and two genera have been synonymized, and one genus has been removed from synonymy (Raven, 1980, 1985; Siliwal, 2009a; Siliwal &Raven, 2010; Siliwal *et al.*, 2010; Guadanucci, 2011). Many more generic revisions and validations of species are expected in the coming years (Siliwal *et al*., 2005).

ENDEMIC MYGALOMORPH DIVERSITY IN INDIA

The mygalomorph spiders are poor at dispersal (Raven, 1980;Bond, 1999, Bond *et al.*, 2006; Siliwal & Molur, 2009b; Siliwal, 2009b), and therefore, a high level of endemism is seen in this group. In Indian mygalomorphs too,a high level of endemism is observed at the species level: of the 89 mygalomorphs reported from India, 87 are endemic to India. In contrast, at the generic level, endemism reduces considerably: of the 27 genera, only six genera are endemic to India and an additional five genera are endemic to South Asia (Table 1). Biogeographic research in India has resulted in different biogeographic elements being recognized in the subcontinent. The species found in the Western Ghats have affinities to African elements, and therefore many genera are presumably Gondwanan relicts, *e.g.*, Tigidia, Neoheterophrictus, Heterophrictusand Heligmomerus(Siliwal *et al.*, 2011; Siliwal *et al.*, 2012). Thirty-seven of the 40 species occurring in the Western Ghats are endemic to the region. In contrast, species occurring in Northeast India have closer affinities with Indo-Chinese or Indo-Malayan elements such asConothele, Damarchus, Phlogeillus and Haplocosmia. Interestingly, 17 of the 19 species reported from Northeast India are endemic to the region. Apart from these, there are genera that are Indian endemics such as *Annandaliella, Thrigmopoeus, Haploclastus, Sasonichus, Scalidognathus* and South Asian endemics such as *Poecilotheria, Diplotheleand Indothele*. The only monotypic genus reported from India is *Sasonichus*, represented by a single species, *Sasonichus sullivani* Pocock, 1900, from Trivandrum, Kerala. It is likely that few species are naturally restricted to certain areas and are found in small numbers, as a result of which they have been never reported from other areas. However, this cannot be confirmed without carrying out a systematic survey throughout the country. With more studies on mygalomorphs being conducted in India,the number of endemic species is expected to increase.

ECOLOGY

Studies in the past were taxonomically-centered, and very little information is available on the ecology and natural history of mygalomorphs of India. Recent descriptions of species include information on natural history, habits and habitats, but ecological studies need to be intensified. Information on ecology and natural history are important for the conservation of a species. The information also educates people on where to look out for spiders in the wild. For example, *Conothele* from Myanmar was reported to be arboreal in habits (Pocock, 1900; Gravely, 1935a), but the species reported from India are strictly ground-burrowing forms (Siliwal *et al.*, 2009c). Similarly, *Chilobrachys* sp. in the Western Ghats was observed to be arboreal nesting in areas with heavy rainfall (pers. obser.).

Population and habitat preference studies have also been initiated recently. Most of these studies remain focused on the ecology of large-bodied tarantulas such as *Poecilotheria* spp., *Thrigmopoeus* spp. and *Chilobrachys* spp. (Molur *et al.,* 2003; Siliwal *et al.*, 2009a), except for one on the trapdoor spider Idiops in the Western Ghats, Karnataka (Gupta, 2010).

Mygalomorphs prefer undisturbed forests and wooded areas. They have been reported from different forest types: wet evergreen forests, semi-evergreen forests, moist deciduous forests, dry deciduous forests, mixed forests, bamboo forests and teak plantations. Usually, most mygalomorphs, including large-bodied tarantulas such as *Thrigmopoeus, Chilobrachys, Neoheterophrictus* and *Lyrognathus*; funnel web mygalomorphs such as *Macrothele* and *Indothele*; trapdoor spiders such as Tigidia and *Conothele*; and the nemesiid Damarchus, are entirely forest dwellers. However, secondarily, some of them have adapted to altered habitats such as scrub lands near human habitations. Some species of *Poecilotheria* primarily prefer old trees in forests and teak or bamboo plantations, but they have also been reported from disturbed and altered habitats such as private plantations (casuarina, banana, tamarind), scrub lands and human habitations that are close to wooded areas. Similarly, the trapdoor spider *Idiops* (in the Western Ghats) (Gupta, 2010) and small-sized tarantulas *Plesiophrictus* (in different locations in India)have also been found in human habitations close to forests (Siliwal, pers. comm.).However, the encounter rate of these spiders in these secondary habitats is less than that in natural forest.

CONSERVATION

Like other Indian fauna, mygalomorphs are also threatened due to habitat loss and fragmentation. An additional threat to large-bodied tarantulas is the illegal pet trade.

Developmental activities such as mining and construction and encroachments of natural resources are degrading forests, and the fragmented habitat is getting altered.The impact of habitat loss and fragmentation is clearly visible in biodiversity-rich areas, namely the Western Ghats and Northeast India. Thus species, including the megafauna, are declining in these areas at a great speed. Conservation efforts have been mainly focused on charismatic fauna or vertebrates, and the status of invertebrates such as mygalomorphs (though they have a long life span) receives no attention.

Mygalomorphs are long-lived spiders that are poor at dispersal, and the species are restricted to few locations. Habitat alteration and degradation can have a major impact on small populations or highly localized species of mygalomorph. For example, *Neoheterophrictus* and *Thrigmopoeus* are ground-burrowing mygalomorphs that prefer very specific habitat areas and need a contiguous habitat for dispersal. As a result of habitat loss and fragmentation, three species of Neoheterophrictusare known only from pockets of forests or wooded areas. Similarly, small ground-burrowing trapdoor spiders of the genus Idiops were observed in clusters (many burrows in a small patch) in suitable habitats in the Western Ghats as a result of habitat loss and fragmentation (Gupta, 2010).Further, any change in the habitat can wipe out a complete population.

In many cases, ground-burrowing mygalomorphs occupy roadside cuts or mud bunds. And very often, roadside cuts are further cut for either maintenance or widening of the road. During this process, many burrows are destroyed, and often spiders get killed by getting buried in the mud or are killed by locals.

Large-bodied tarantulas are often killed by locals who find these spiders near human habitations or in forests. They do this mainly due to a lack of education, fear and myths prevailing regarding spiders. Tarantula bites are very painful but are not lethal to humans.

Another major threat in Northeast India and the Western Ghats is that of slash-and-burn agriculture practices, which raise the temperature of burrows and cause ground mygalomorphs to die. However, some deep-burrowing mygalomorphs and trapdoor spiders have been able to escape small fires in forests (Molur *et al*., 2003; Gupta, 2010).

PET TRADE

There is a long history of keeping tarantulas in captivity, earliest record is from 1700 AD (Molur & Siliwal, 2004; Smith, pers. comm.). It got popularized as a hobby in the late 19th century in Europe and North America. South and Central American tarantulas (*Brachypelma* spp., *Avicularia* spp.) were in great demand and were collected extensively from the wild for the pet trade. To save these species from extinction, *Brachypelma* spp. and *Aphonopelma* spp. were included in the Appendix II of the CITES in 1994 (Locht, 1999;M'rabet, 2005). After which, trade shifted to South Asian tarantulas, which morphologically resembled the South American tarantulas. A total of 13 species of Indian tarantulas are in the pet trade (Table 2). This includes all *Poecilotheria* spp., *Thrigmopoeu*s spp., *Lyrognathus* spp. The Pet trade in India continues because these spiders are not listed under the Wildlife Protection (1972) Act or are CITES listed. As these species are long-lived, it takes more than four years for a female to mature and moreover, captive breeding and rearing is a time-consuming and tedious process. Therefore, collecting tarantulas from the wild gives quick profit to traders. Many of these species (e.g., *Poecilotheria metallica, Thrigmopoeus insignis, Haploclastus nilagiris*) are restricted to small patches of forest and effect of pet-trade on wild population can be critical for species survival. Even species like *Poecilotheria regalis*, with a wide range of distribution could be threatened with local extinction due to collection for pet- trade. Most of these tarantulas population status in the wild is poorly known.

RED LIST

In 2000, the Sri Lankan government and the US Fish and Wildlife Service proposed that the genus *Poecilotheriabe* included in the appendices of CITES due to the increasing trade in these spiders. But they were not included in CITES because of a lack of information on the population status, distribution, ecology and biology of these spiders. Subsequently, studies were initiated to collect primary data on the distribution and population status of Indian tarantulas in the wild. And based on the published literature and data collected during recent surveys on tarantulas in India, 14 species of theraphosid were listed in the IUCN Red List in 2008 (Table 3, Molur *et al*., 2008).Eight of the 14 species are threatened with extinction. Two species are Critically Endangered, four species are Endangered and two species are Vulnerable due to various threats including the pet trade and the restricted nature and small size of the populations. Conservation plans need to be framed for threatened species and put into action before complete populations get extinct in the wild.

CONSERVATION PRIORITIES

Distribution and diversity studies: Very few areas have been surveyed properly for mygalomorphs. Most of the records obtained before independence were based on chance encounters. Though recent surveys have been focused on mygalomorphs, surveys have remained restricted to a few selected spots in the Western Ghats, Eastern Ghats and east and northeast India, and most areas in the country remain unsurveyed. A systematic survey is required for the whole country to get an overall picture of the distribution and diversity of mygalomorphs in India.

Population status: Of the 14 species of tarantula in the Red List, five species are Data Deficient due to a lack of information on their populations. These species should be a priority for population studies in the wild and for future assessments.Further, a study should be carried out to understand the impact of the pet trade on the wild populations of these tarantulas.

Biology: The life cycle of Indian tarantulas is very poorly known. Therefore, in-situ as well as ex-situ studies should be carried out to understand the life span and breeding biology of Indian tarantulas. This will help in gaining an understanding of the long-term impact of various threats on wild populations and can be included in conservation management plans for threatened tarantulas.

Taxonomic revisions: Most of the descriptions of mygalomorph species are old and outdated.For these species, re-description based on examination of type specimens (often located in European museums) or re-collection of fresh specimens from their type localities is required. This will help revise the Indian mygalomorph genera. Taxonomic confusion can be resolved with the help of advanced molecular techniques.

Education and awareness: With sporadic news regarding tarantula bites and myths prevailing about tarantula venom, it is necessary to create awareness programmes for locals about the positive role of these spiders and to educate them about the misconceptions related to the poisonous nature of these spiders. Also, to have a control on the illegal collection and smuggling of tarantulas from India, forest officials, central government officials and custom officials should also be educated about the existing pet trade involving Indian tarantulas. Further, training needs to be provided on what to do with confiscated animals.

Legal protection:To maintain a check on smuggling of tarantulas, it is necessary to get some of these spiders listed under the Wildlife Protection Act or CITES. At international ports, the customs need to keep a strict watch to prevent anyone fromsmuggling these spiders out of the country.

Liaison with customs officers in other countries (*e.g.,* USA, Mexico, Germany) will permit a useful list of known or convicted smugglers to be made. All customs officers and park staff can be alerted when these people enter the country. In other countries, the use of these data and searches on outgoing luggage has ensured that the loss of fauna is minimal.

Conservation:A few hot spots should be selected, and the tarantula populations in these areas should be monitored. Local communities and the forest departments need to be motivated and trained to carry out long-term monitoring programmes.

CONCLUSIONS

With the present revived interest in mygalomorph studies in India, more species are expected to be discovered. Along with the distribution and taxonomic studies, there is a need to take up conservation-oriented studies on threatened tarantula species to ensure their survival in the wild. Sensitizing locals, foresters and decision makers can help the long-term conservation of tarantulas. Also, a strict implementation of laws can ensure that the illegal pet trade existing in the country is restricted.

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Table 1. List of Indian mygalomorphs with their distribution records

Family	Species	Sex	Locality	Distribution
Atypidae	*Atypus sutherlandi* Chennappaiya, 1935*	M,F	Kalimpong, in Darjeeling District, West Bengal	India
Barychelidae	*Diplothele gravelyi* Siliwal *et al.*, 2009*	F	Jadeshwar,Huma, Ganjam District, Orissa	India
Barychelidae	*Diplothele tenebrosus* Siliwal *et al*., 2009*	F	Orissa: Satkosia Wildlife Sanctuary, Angul District	India
Barychelidae	*Diplothele walshi* O. P.-Cambridge, 1890	M,F	Barkuda Island, Orissa	India
Barychelidae	*Sason andamanicum* Simon, 1888*	M,F	Andaman Island	India
Barychelidae	*Sason rameshwaram* Siliwal & Molur, 2009*	M,F	Rameshwaram Island, Mandapam, Ramnathpuram District, Tamil Nadu	India
Barychelidae	*Sason robustum* (O. P.-Cambridge, 1883)	M,F	Tirupati hills, Horsleykondain Chittoor District, in Andhra Pradesh; Madras city, Rameshwaram Island, Nerkandram, Chingleput District, in Tamil Nadu; Trivandrum, Travancore in Kerala; Anuradhapura, in Sri Lanka	India, Sri Lanka, Seychelles
Barychelidae	*Sasonichus sullivani* Pocock, 1900*	M	Trivandrum, Kerala	India
Barychelidae	*Sipalolasma arthrapophysis* (Gravely, 1915)*	M,F	Barkul, in southeast Orissa	India
Barychelidae	*Tigidia nilgiriensis* Sanap, Mirza & Siliwal, 2011*	F	Kothagiri, Tamil Nadu	India
Barychelidae	*Tigidia rutilofronis* Sanap, Mirza &Siliwal, 2011*	F	Maruthamalai, Coimbatore District, Tamil Nadu	India

Barychelidae	*Tigidia sahydari* Siliwal, Gupta & Raven, 2011*	F	Dandeli, Uttara Kannada District, Karnataka	India
Ctenizidae	*Conothele vali* Siliwal *et al.,* 2009*	F	Near Shurbi village, Tawang District, Arunachal Pradesh	India
Ctenizidae	*Conothele varvarti* Siliwal *et al*., 2009*	F	Barehipaniroad, Chahala Range, Similipal Tiger Reserve, Orissa	India
Ctenizidae	*Latouchia cryptica* (Simon, 1897)*	M	The Deccan	India
Dipluridae	*Indothele dumicola* (Pocock, 1900)*	M,F	Poona, Maharashtra	India
Dipluridae	*Indothele mala* Coyle, 1995*	F	Exact location not known	India
Dipluridae	*Indothele rothi* Coyle, 1995*	F	Exact location not known	India
Dipluridae	*Ischnothele indicola* Tikader, 1969*	M,F	Khasi and Jaintia hills, Meghalaya	India
Hexathelidae	*Macrothele vidua* Simon, 1906	M,F	Kalimpong, in Darjeeling District,and Kurseong, West Bengal	India
Idiopidae	*Heligmomerus barkudensis* (Gravely, 1921)*	M,F	Barkuda Island, Orissa	India
Idiopidae	*Heligmomerus biharicus* (Gravely, 1915)*	M	Sahibgunge, Bihar	India
Idiopidae	*Heligmomerus prostans* Simon, 1892*	F	Kodaikanal, Palni Hills, Tamil Nadu	India
Idiopidae	*Idiops bombayensis* Siliwal, Molur & Biswas, 2005*	M,F	Bombay, Matheran, Maharashtra	India
Idiopidae	*Idiops constructor* (Pocock, 1900)	M,F	Chingleput, Yercaud (in the Shevaroy Hills) in Tamil Nadu; Horsleykonda, Chittoor District in Andhra Pradesh; Panchgani (Satara District), Medha, Yenna Valley (Satara District), in Maharashtra	India
Idiopidae	*Idiops fortis* (Pocock, 1900)*	F	Exact location not known	India
Idiopidae	*Idiops fossor* (Pocock, 1900)*	M	The Deccan	India
Idiopidae	*Idiops garoensis* (Tikader, 1977)*	M	Degrangiri, Garo Hills, Meghalaya	India
Idiopidae	*Idiops madrasensis* (Tikader, 1977)*	F	Kulasekeram, Madras District, Tamil Nadu	India
Idiopidae	*Idiops rubrolimbatus* Mirza and Sanap, 2012*	M,F	Mumbai, Maharashtra	India
Idiopidae	*Idiops kassensis* Mirza *et al.*, 2012*	M,F	Kaas Plateau, Panchagani, Satara District, Maharashtra	India
Idiopidae	*Scalidognathus nigriaraneus* Sanap and Mirza, 2011*	F	Dodabetta peak, Ooty, Nilgiri District, Tamil Nadu	India
Idiopidae	*Scalidognathus tigerinus* Sanap and Mirza, 2011*	F	Maruthamalai, Coimbatore District, Tamil Nadu	India

Idiopidae	*Scalidognathus montanus* (Pocock, 1900)*	F	Yercaud, in Shevaroy Hills, Tamil Nadu	India
Nemesiidae	*Damarchus assamensis* Hirst, 1909*	M,F	Sibsagar, Assam; Gmatia in Birbhum District, West Bengal	India
Nemesiidae	*Damarchus bifidus* Gravely, 1935*	M	Tindharia (Darjeeling District), Kalimpong, Sureil, Gopaldhara, West Bengal	India
Nemesiidae	*Damarchus excavatus* Gravely, 1921*	F	Barkuda Island, Orissa	India
Theraphosidae	*Annandaliella ernakulamensis* Jose & Sebastian, 2008*	M	Boothathankettu forests, Ernakulam District, Kerala	India
Theraphosidae	*Annandaliella pectinifera* Gravely, 1935*	M,F	AgriculturalCollege, Coimbatore, Tamil Nadu	India
Theraphosidae	*Annandaliella travancorica* Hirst, 1909	M,F	Kulattupuzha; Trichur; Cochin State Forest (Parambikulam Wildlife Sanctuary) in Kerala	India
Theraphosidae	*Chilobrachys fimbriatus* Pocock, 1899	M,F	Khandala, Jaoli (Satara); Hoshali in Shimoga District in Mysore state (now in Karanataka). Recent observations: Borivali National Park, Amba Valley, Amboli, Matheran (Maharashtra); Castle Rock (Goa and Karnataka)	India
Theraphosidae	*Chilobrachys himalayensis* (Tikader, 1977)*	M	Birch Hill, Darjeeling, eastern Himalaya, West Bengal	India
Theraphosidae	*Chilobrachys khasiensis* Tikader, 1977*	F	Umshining, Khasi and Jaintia hills, Meghalaya	India
Theraphosidae	*Chilobrachys assamensis* Hirst, 1909*	M,F	Sibsagar, Assam	India
Theraphosidae	*Chilobrachys femoralis* Pocock, 1900*	M	Nasik, Maharashtra	India
Theraphosidae	*Chilobrachys flavopilosus* (Simon, 1884)	M,F	Exact location in India not known	India, Myanmar
Theraphosidae	*Chilobrachys fumosus* (Pocock, 1895)	M,F	Burroi in Dafla Hills, Arunachal Pradesh; Sureil,Darjeeling; Kurseong, eastern Himalaya	India
Theraphosidae	*Chilobrachys hardwicki* (Pocock, 1895)	M,F	Shahjahnpur in North-West provinces; Bilaspur, in Central Province; Chota Nagpur; Burdwan; Dharhara (Monghyr District),Sahibgunge in Bihar; Chakardharpur (Singbhum District) in Chota Nagpur; Gmatia (Birbhum District) and Murshidabad, West Bengal	India
Theraphosidae	*Chilobrachys stridulans* (Wood Mason, 1877)	M,F	Aideo, Goalpara, Sibsagar, Silcuri in-Cachar in Assam; Punkabari in Sikkim (=West Bengal), Sylhet, Assam (now in Bangladesh)	India, Bangladesh
Theraphosidae	*Chilobrachys thorelli* Pocock, 1900	M	Sadiya, Assam	India
Theraphosidae	*Haploclastus cervinus* Simon, 1892*	F	Shembaganur and Kodaikanal in Palni Hills in Tamil Nadu	India
Theraphosidae	*Haploclastus kayi* Gravely, 1915*	F	Parambikulam Wildlife Sanctuary, Kerala	India

Theraphosidae	*Haploclastus nilgirinus* Pocock, 1899*	F	Nilgiri Hills; Savarimullay, Vandiperiyar, Travancore, Kerala	India
Theraphosidae	*Haploclastus satyanus* (Barman, 1978)*	F	Cantonment area, Shillong, Meghalaya	India
Theraphosidae	*Haploclastus tenebrosus* Gravely, 1935*	M	High Wavy Mountain, Madura District, Tamil Nadu	India
Theraphosidae	*Haploclastus validus* (Pocock, 1899)	F	Matheran, Mumbai, Bhimshankar, Maharashtra	India
Theraphosidae	*Haplocosmia himalayana* (Pocock, 1899)*	M,F	Dehra Dun, Uttaranchal	India
Theraphosidae	*Heterophrictus bhori* (Gravely, 1915)*	F	Parambikulam Wildlife Sanctuary, Kerala	India
Theraphosidae	*Heterophrictus milleti* Pocock, 1900	F, M	Nasik; Eastern Poona; Jauli; Mahabaleshwar, in Satara; Bhimashankar; in Maharashtra	India
Theraphosidae	*Lyrognathus crotalus* Pocock, 1895*	M,F	North India, Shillong, Meghalaya	India
Theraphosidae	*Lyrognathus saltator* Pocock, 1900*	F	North Khasi Hills, Meghalaya	India
Theraphosidae	*Neoheterophrictus crurofulvus* Siliwal et al., 2012*	M,F	Dandeli Wildlife Sanctuary, Uttara Kannada, Karnataka	India
Theraphosidae	*Neoheterophrictus sahyadri* Siliwal et al., 2012*	M,F	Dandeli and Anshi Tiger Reserve, Uttara Kannada, Karnataka	India
Theraphosidae	*Neoheterophrictus uttarakannada* Siliwal et al., 2012*	F	Anshi and Dandeli Wildlife Sanctuary, Uttara Kannada, Karnataka	India
Theraphosidae	*Phlogiellus subarmatus* (Thorell, 1891)*	M,F	Nancowry in the Nicobar Islands	India
Theraphosidae	*Plesiophrictus linteatus* (Simon, 1891)*	F	Pondicherry	India
Theraphosidae	*Plesiophrictus nilagiriensis* Siliwal, Molur & Raven, 2007*	F	Mettupalayam, Coimbatore, Tamil Nadu	India
Theraphosidae	*Plesiophrictus blatteri* Gravely, 1935*	M,F	Panchgani, Satara District, Maharashtra	India
Theraphosidae	*Plesiophrictus collinus* Pocock, 1899*	F	Yercaud, in Shevaroy hills, Madras Presidency (Tamil Nadu)	India
Theraphosidae	*Plesiophrictus fabrei* (Simon, 1892)*	F	Madura, South India	India
Theraphosidae	*Plesiophrictus madraspatanus* Gravely, 1935	M,F	Madras city, Chingleput District, Velacheri, Nagalapuram Hills, Kambakkam Hills, in Tamil Nadu	India
Theraphosidae	*Plesiophrictus meghalayaensis* Tikader, 1977*	M,F	Fruit garden, Nongrim Hills, Shillong, Meghalaya	India
Theraphosidae	*Plesiophrictus millardi* Pocock, 1899*	M, F	Matheran, Uran, Maharashtra	India
Theraphosidae	*Plesiophrictus raja* Gravely, 1915*	F	Kavalai, Cochin State Forest, Kavalai, Kerala	India

Theraphosidae	*Plesiophrictus satarensis* Gravely, 1915*	M,F	Medha, in Yenna Valley; Umbri, Taloshi, Helvak, Kembsa, in Koyna Valley of Satara District, in Maharashtra	India
Theraphosidae	*Plesiophrictus sericeus* Pocock, 1900*	F	Poona, Maharashtra	India
Theraphosidae	*Poecilotheria tigrinawesseli* Smith, 2006	M,F	Anantagiri, Araku, Paderu, in Andhra Padesh	India
Theraphosidae	*Poecilotheria formosa* Pocock, 1899	F	Kadiampatti and Mallapuram, in Salem District, in Tamil Nadu	India
Theraphosidae	*Poecilotheria hanumavilasumica* Smith, 2004	M,F	Rameshwaram Island, Mandapam, Ramanathapuram District, Tamil Nadu	India
Theraphosidae	*Poecilotheria metallica* Pocock, 1899*	F	Nandyal-Giddalur road and Gooty, in Andhra Pradesh	India
Theraphosidae	*Poecilotheria miranda* Pocock, 1900*	F	Chota Nagpur, Kharagpur Hills, Chaibassa, Singbhum District of Chota Nagpur; Simlipal Tiger Reserve, Orissa	India
Theraphosidae	*Poecilotheria regalis* Pocock, 1899	M,F	Coorg, Mysore, Bangalore in Karnataka; Sengottai, Mudumalai, Masinagudi, Avinashi, Nilgiri Hills, Moongilpallam in Anaikatti, Puttapathi (Siruvani),Theppakadu,Arakkonam (Arcot District), in Tamil Nadu; Anamalai Hills, in Kerala; Madanapalle, Biarapur Cheruvu, Thummalabailu, Shikharam, Sunipenta, Paldhara Panchdhara, Nandyal-Giddalur road, in Andhra Pradesh	India
Theraphosidae	*Poecilotheria rufilata* Pocock, 1899*	M,F	Trivandrum, Mookuthala Sacred Grove, Nammamukku, Malapuram, in Kerala	India
Theraphosidae	*Poecilotheria striata* Pocock, 1895	M,F	Mysore, Dandeli Wildlife Sanctuary, in Karnataka; Puttapathi (Siruvani), Tamil Nadu; Trivandrum, Parambikulam Wildlife Sanctuary, Peechi, Thrissur, Vazhachal Forest, Pattikadu Reserve Forest, in Kerala	India
Theraphosidae	*Selenocosmia javanensis* (Walckenaer, 1837)	M,F	Lesser Nicobar; Java	India, Malaysia to Sulawesi
Theraphosidae	*Selenocosmia kulluensis* Chamberlin, 1917*	M	Kullu Valley, Himachal Pradesh	India
Theraphosidae	*Selenocosmia sutherlandi* Gravely, 1935*	M	Kalimpong, Darjeeling District, West Bengal	India
Theraphosidae	*Thrigmopoeus insignis* Pocock, 1899	M,F	Kanara Ghats, Castle Rock, Dandeli Wildlife Sanctuary, North Canara, in Karnataka	India
Theraphosidae	*Thrigmopoeus truculentus* Pocock, 1899	M, F	Karwar, Coorg, in Karnataka; Amboli, in Maharashtra	India

Note: species with * mark are only known from the type locality

Table 2. List of Indian species of mygalomorph in the pet trade

S . No.	Scientific name	Common name in pet trade	Status in pet trade
1.	*Chilobrachys fimbriatus* Pocock, 1899	Indian Violet	Very common
2.	*Chilobrachys hardwicki* (Pocock, 1895)	Common Indian Yellow-brown Tarantula	Rare
3.	*Lyrognathus crotalus* Pocock, 1895	-	Common
4.	*Haploclastus nilgirinus* Pocock, 1899	Nilgiri Dark Mustard	Common
5.	*Poecilotheria regalis* Pocock, 1899	Indian Ornamental Tarantula	Very common
6.	*Poecilotheria miranda* Pocock, 1900	Bengal Spotted Ornamental	Very common
7.	*Poecilotheria formosa* Pocock, 1899	Salem Ornamental Tarantula	Common
8.	*Poecilotheria rufilata* Pocock, 1899	Red Slate Ornamental Tarantula	Very common
9.	*Poecilotheria metallica* Pocock, 1899	Gooty Ornamental	Very common
10.	*Poecilotheria striata* Pocock, 1895	Mysore Ornamental	Very common
11.	*Poecilotheria tigrinawesseli* Smith, 2006	Ivory Ornamental	Common
12.	*Thrigmopoeus truculentus* Pocock, 1899	Lesser Goa Mustard	Very common
13.	*Thrigmopoeus insiginis* Pocock, 1899	Kanara Ghats Mustard	Common

Table 3. List of Indian tarantula spiders in the IUCN Red List and their categories

Scientific name	Common names	Category	Criteria
Chilobrachys fimbriatus Pocock, 1899	Fimbriated Striated Burrowing Spider, Indian Violet	Least Concern	
Chilobrachys hardwicki (Pocock, 1895)	Eastern Indian Striated Burrowing Spider	Least Concern	
Haploclastus kayi Gravely, 1915	Parambikulam Large Burrowing Spider	Endangered	B1ab(ii,iii)
Poecilotheria formosa Pocock, 1899	Beautiful or Finely Formed Parachute Spider, Salem Ornamental	Endangered	B1ab(i,ii,iii)+2ab(i,ii,iii)
Poecilotheria hanumavilasumica Smith, 2004	Rameshwaram Parachute Spider, Rameshwaram Ornamental	Critically Endangered	B1ab(ii,iii,iv,v)+2ab(ii,iii,iv,v)
Poecilotheria metallica Pocock, 1899	Peacock Parachute Spider, Gooty Tarantula, Metallic Tarantula, Peacock Tarantula	Critically Endangered	B1ab(iii)
Poecilotheria miranda Pocock, 1900	Wonderful Parachute Spider, Bengal Ornamental	Endangered	B1ab(iii)
Poecilotheria nallamalaiensis Rao *et al*., 2007*	Nallamala's Parachute Spider	Data Deficient	
Poecilotheria regalis Pocock, 1899	Regal or King Parachute Spider, Indian Ornamental	Least Concern	
Poecilotheria rufilata Pocock, 1899	Reddish or Rufus Parachute Spider,Travancore Slate-Red, Red Slate Ornamental	Endangered	B1ab(ii,iii)
Poecilotheria striata Pocock, 1895	Striped or Striated Parachute Spider, Mysore Ornamental	Vulnerable	B1ab(ii,iii)+2ab(ii,iii)
Poecilotheria tigrinawesseli Smith, 2006	Anantagiri's Parachute Spider	Data Deficient	

Thrigmopoeus insignis Pocock, 1899	Notable Large Burrowing Spider	Vulnerable	B1ab(ii,iii)+2ab(ii,iii)
Thrigmopoeus truculentus Pocock, 1899	Karwar Large Burrowing Spider	Near Threatened	B1ab(ii,iii)

*Note: This species has been synonymized with *P. formosa*.

INSECT FAUNA OF STATES AND UNION TERRITORIES IN INDIA

Kailash Chandra
Zoological Survey of India, M Block, New Alipore, Kolkata 700053, India.
email: kailash611@rediffmail.com

ABSTRACT
The paper presents an account of the current insect biodiversity in India. For the first time, the insect species diversity of states and union territories is described, and the gaps are highlighted by region and group. An introduction is provided to threatened species of insects, and a strategy for conservation of insects is also discussed.

INTRODUCTION
Insects are the most exuberant manifestations of earth's life. It defies imagination to understand how their simple unifying body plan has been modified to produce an enormous variety of species and how it has been able to exploit almost every conceivable type of environment from the equator to the arctic region and from sea level to the snowfields of the highest mountains, on land, in air and in water—almost everywhere. The class Insecta or the higher taxa-subphylum Hexapoda (which additionally includes Collembola, Protura and Diplura) is the world's most species-rich group of organisms, with over 1 million described species. They are most diverse in tropical forests, where the un-described fauna has been estimated to comprise 5 to 50 million species. Hexapods are a well-established monophyletic group, characterized by the presence of three major body divisions—head, thorax, abdomen—and a single pair of locomotory appendages on each thoracic segment. Some primitive insects have retained appendages on the abdominal segments, but these are much smaller and less functional than those on the thorax. The more derived groups of insects usually have a pair of wings on each of the mesothoracic and metathoracic segments, which have been lost or modified in some groups, especially the Diptera.

The fossil record of insects goes back to the earliest record of terrestrial life, with Collembola and lower insects recorded from the lower Devonian, almost 400 million years ago, and possibly, there are even earlier traces from the Silurian. Insects have been prominent members of the fossil record ever since, with most prominent major groups having been preserved from late Paleozoic or early Mesozoic formations (200-250 million years ago).

There is ample proof that insects were systematically investigated many centuries before Aristotle. Hymns of Atharva Veda on the control of insects attacking crops reflect the variety of pests. Manudharma Sastra (1000 BC) identifies bees and biting insects such as mosquitoes and ants, while the treatise of Charaka (1200 BC) on bees and Shushmita's (100-200 AD) work on stings and his classification of ants (piplika) and flies (mahashikala) are of interest. Amarasimha coined the term shashpada for the Hexapoda nearly 1000 years ago (Ananthakrishnan, 2000).

Modern entomological systematic work was initiated with the establishment of the East India Company, through the abiding interest of amateur entomologists in the armed, civil, forest and medical services. The first entomologist who made an extensive study of Indian insects was J. C. Fabricius (1745-1808), and the publication of Carl Linnaeus' (1758) Systema Naturae (10th edition) provided the earliest record of Indian insects, with descriptions of 28 species. Westwood's (1847) 'Cabinet of Oriental Insects' provides a selection of some of the rarer and more beautiful species of insects native to India (Ananthakrishnan, 2000). Since much of the pioneering work was carried out by British amateur entomologists, who explored various parts of the Indian subcontinent , particularly the hilly areas of the eastern and western Himalaya, the Western Ghats and popular places, much of their material was taken to their country for identification. These efforts led to the publication of several volumes on the Fauna of British India. With the establishment of the ZSI at Kolkata in 1916, regular surveys were carried out in all parts of India including unexplored and inaccessible areas. The Forest Research Institute (FRI), Dehradun, presently under the Indian Council of Forest

Research and Education (ICFRE), and the Indian Agricultural Research Institute (IARI), under the Indian Council of Agricultural Research (ICAR), have contributed to our knowledge of economically important insects of forests and agriculture, respectively.

The kingdom Animalia is represented by 15,52,319 species that have been described so far globally in 40 phyla in a new evolutionary classification. The phylum Arthropoda alone includes 12,42,040 species, constituting about 80% of the total number of species. The most successful group, Insecta, accounts for about 66% (10, 20,007 species in 39 orders) of all animals. The most successful insect order, Coleoptera, represents about 38% (3, 87,100 species) of the insect species of the world (Zhang, 2011). Compilations on the insect fauna of India have been produced from time to time. Maxwell and Howlett (1909) published the book Indian Insect Life, wherein 25,700 species of insect were reported from the Indian region, including adjacent countries. Beeson (1941) and Menon (1965) estimated the number of species from India to be 40,000 and 50,000, respectively. In recent times, Varshney (1997) reported 51,450 species under 589 families. Subsequently, Varshney (1998) reported the occurrence of 59,353 species of insect belonging to 619 families in India.

TAXONOMIC ACCOUNT

KINGDOM ANIMALIA

PHYLUM ARTHROPODA

SUBPHYLUM HEXAPODA

The traditional morphology-based or appearance-based insect classifications have given way to modern classification systems based on evolutionary history and genetic data. All the insects were formerly included in the order Insecta, which is currently classified as Hexapoda, but recently scientists have excluded the orders Collembola, Protura and Diplura from the class Insecta, and these have been upgraded to the class level.

COLLEMBOLA

Commonly known as springtails, these are small, wingless, soft-bodied hexapods measuring usually between 0.2 and 5.0 mm in length and possessing a spring-like jumping organ, the furcula, underneath the fourth abdominal segment. The mouthparts are entognathous. The antennae are usually four-segmented. Compound eyes may be present or absent. There are 8130 described species of Collembola worldwide (Janssens, 2012). The Indian Collembola fauna is represented by 299 species in 103 genera under 19 families (Mandal, 2009), of which 45 species are endemic.

PROTURA

Proturans, with entognathous, piercing mouthparts, are small, wingless, un-pigmented hexapods measuring less than 2.5 mm in length. Antennae and eyes are absent. The anterior legs sensory, and all tarsi are one-segmented, with a single claw. The front legs serve as antennae. A unique feature is the telson tail, which is common in crustaceans but is absent in other insects. The telson tail is used for locomotion and for defense. There are 804 described species of Protura worldwide. From India, presently 20 species have been reported in 10 genera under 3 families (Prabhu, 1986), of which 17 species are endemic.

DIPLURA

Diplurans are elongate, wingless hexapods usually found in moist soil, forest leaf litter and humus and measure 3-28 mm in length. The japygids are easily identified by the pincers at the end of the abdomen (modified cerci), while in the campodeids the cerci are not pincer-like and many segments have long hair. The mouthparts are entognathous, and the antennae are many-segmented. The flagellar segments are provided with muscles. Compound eyes and ocelli are absent. The tarsi have 1 or 2 segments. The abdomen is provided with appendages formed from lateral styli, and cerci are present. The world fauna of Diplura comprises 976 species, and the Indian fauna is represented by 18 species in 9 genera under 4 families (Mandal, 2010b), of which 12 species are endemic.

CLASS INSECTA (TRUE INSECTS)

SUBCLASS APTERYGOTA

Archaeognatha and Zygentoma (Thysanura): The order Thysanura includes some of the most primitive, wingless insects. They are covered with silvery scales. The scales give rise to the common name “silverfish”. The order is cosmopolitan. These insects are larger than the other members of the subclass Apterygota and are easily distinguishable from the other closely related groups by their long, many-segmented antennae, 2 anal cerci and single median telson at the terminal part of the abdomen. The mouthparts are ectognathous, adapted for biting. Over 1200 species of Thysanura have been reported worldwide (Mendes, 1990). In India, the suborder Archaeognatha is represented by 10 species belonging to 6 genera and 2 families, and the suborder Zygentoma includes 28 species belonging to 15 genera and 3 families (Mandal, 2010c). Among the known taxa, 23 species are endemic to India.

SUBCLASS PTERYGOTA

EXOPTERYGOTA

EPHEMEROPTERA

Commonly known as mayflies, this ancient group of aquatic insects evolved 290 million years ago. Mayflies are found in unpolluted wetlands, especially streams and lakes. The adults have a life span of a few hours to a few weeks, depending upon the species. These insects are important benthic macro-invertebrates and play a major role in the degradation of organic matter. They are also reliably used as bio-indicators of water and habitat quality. More than 3000 species of mayfly belonging to 400 genera and 42 families are presently known globally. Of these, 124 species under 46 genera and 12 families have been reported from India, including 72 species endemic to India (ZSI, 2012).

ODONATA

These insects are commonly known as dragonflies (Anisoptera) and damselfies (Zygoptera). They are amphibiotic insects that spend the major part of their life in freshwater ecosystems. The adults are flying insects and have short life spans. The larvae are carnivorous and voracious feeders, while the adults are predaceous insects. This order includes approximately 6000 species in 37 families, under three suborders, namely Zygoptera, Anisozygoptera and Anisoptera. The first consolidated work on Indian Odonata is by Fraser (1933, 1934, 1936), published in three volumes in the Fauna of British India series. Recently, Prasad and Varshney (1995) published a check-list of 499 species and subspecies of Odonata from the Indian region. Presently, 463 species belonging to 139 genera under 19 families are listed from India (ZSI, 2012), of which 115 species are endemic.

PLECOPTERA

These are commonly known as stoneflies and are generally found in high-altitude hill streams of cold temperate regions. The nymphs are found under stones in these streams, and the adults are weak fliers, found near the streams on tree trunks, stones or bushes. Globally, 3788 species of stonefly belonging to 286 genera and 16 families are known; 116 species under 25 genera and 8 families have been reported from India (ZSI, 2012), of which 66 species are endemic.

ORTHOPTERA

This order includes grasshoppers, crickets and katydids, characterized by the presence of enlarged hind legs, which are used to jump great distances. Many katydids are masters of camouflage, with green, leaf-like wings bearing markings that resemble leaf veins, fungal infections and even insect-feeding damage. Some grasshoppers and katydids are strong fliers, whereas crickets are usually much more likely to stay on the ground. Most male Orthoptera produce sound to attract mates, and the calls of katydids and crickets are an integral part of the evening chorus in tropical regions of the world. They are mostly herbivorous, while some are predators. Altogether, 24,276 species of Orthoptera are known globally. A total of 1033 species belonging to 398 genera under 21 families are known from India (Shishodia *et al.,* 2010), of which 563 species are endemic.

PHASMIDA

The walking-sticks are species with long, stick-like bodies covered in warts, bumps and spines. The flattened species, camouflaged like leaves, are appropriately referred to as leaf insects, and all these are herbivorous. Out of 3029 species of leaf insects and stick insects belonging to 391 genera and 7 families known globally, 144 species under 41 genera and four families have been reported from India (ZSI, 2012), 99 of these species being endemic to the country.

DERMAPTERA

Earwigs are a distinctive group of insects that have a pair of forceps-like appendages at the posterior apex of the abdomen. Wings are absent in some species, and when wings are present, they are modified, such that the forewings are shortened and hardened and the hind wings are extensively folded, exposing most of the abdomen. These species are omnivorus, predatory or herbivorous and are nocturnal. They are found in leaf litter, under rocks, in rotten logs or in any hidden crevice. Presently, 1978 species of earwigs are known globally, of which 298 species belonging to 75 genera and 7 families have been reported from India (ZSI, 2012). Among the known taxa, 117 species are endemic to India.

EMBIOPTERA

These insects are referred to as web-spinners. They form a small group of soft–bodied, relatively small, gregarious insects and are found in most tropical and warm temperate climates. The web-spinners are an unusual group of small insects that live in silk galleries of their own production. They are narrow-bodied and wingless (except for some males) and have the first tarsal segment swollen and filled with silk glands. The galleries they spin are found under bark, beneath stones or in the open in more humid regions; from these galleries they feed on vegetable debris, rotten wood, moss or lichens. There are 464 extant embiid species worldwide (Zhang, 2011). In India, the order is represented by 31 species belonging to 5 genera under two families, namely Embiidae and Oligotomidae (ZSI, 2012), of which 14 are endemic to the country.

BLATTODEA

Commonly known as cockroaches, these are flattened terrestrial insects. Usually cryptic and nocturnal scavengers, they were earlier included in the order Dictyoptera. They vary in shape and size from small, delicate species a few millimeters in length to large, bulky forms 6 cm long. They are usually cryptically colored. Presently, 7,314 species of cockroach are known globally, of which 186 species belonging to 58 genera and 12 families have been reported from India (ZSI, 2012). Of these, 60 species are endemic.

MANTODEA

The praying mantids are voracious predators. They have modified, spiny, raptorial forelegs that grasp and crush their prey (usually other insects; very rarely, even small vertebrates). Most mantids are green or brown in colour and resemble leaves or petals of flowers. The camouflage assists them in resisting attacks by predators and in avoiding detection by their prey. Presently, about 2400 species of mantids are known globally, of which 174 species belonging to 72 genera and 11 families have been reported from India (ZSI, 2012). Among the known taxa, 77 species are endemic to India.

ISOPTERA

Commonly known as termites and white ants, these are the only eusocial group of insects other than the Hymenoptera. They feed on cellulose from wood, leaves and plant debris, which is digested in their guts by symbiotic microbial flagellate protozoans or spirochaete bacteria. They have strong social organization, division of labour amongst castes, superb architectural ability, concealed and symbiotic mode of life. These insects are notable for their pest status and the fact that they release methane, a potent greenhouse gas, into our environment. Presently, 2864 species of termites under 195 genera distributed over 9 families are known globally, of which 271 species belonging to 52 genera and 7 families have been reported from India (ZSI, 2012). Of these, 172 species are endemic to the country.

PSOCOPTERA

They are commonly known as bark and book lice. These small insects are less than 1 cm in length, have large, globular heads and rounded bodies, and may or may not bear 2 pairs of wings. They live on plants, on bark, in leaf litter and sometimes in human habitation, and their food is plant, fungus and dead-insect debris. Out of 5720 species of bark and book lice reported from around the world, only 105 species belonging to 16 families have been reported from India. Of these, 15 are endemic.

PHTHIRAPTERA

Commonly known as lice, these are specialized ectoparasites of mammals and birds. Some species, such as the chewing lice, feed on skin, hair or feathers, whereas others, such as the sucking lice, suck blood from their hosts. All these are small, wingless, flattened insects found only on their hosts. So far, 5102 species of lice have been reported globally. A total of 400 species have been reported from India, including 16 endemic species.

HEMIPTERA

This order includes the Heteroptera, or true bugs, and the Homoptera, made up of the cicadas, leaf-hoppers, tree-hoppers, plant-hoppers, aphids, whiteflies, scales and others. All have distinctively modified mouthparts that are in the form of piercing-sucking beaks that they use to obtain food. The predatory species pierce their prey, usually other insects, injecting digestive enzymes to kill and begin the process of digestion. Predation is restricted to some heteropterans—a few also feed on vertebrate blood. The majority of the heteropterans and all the homopterans are plant feeders. Most species are terrestrial, and some are aquatic. Altogether, 103,590 species of Hemiptera belonging to 152 families and 4 suborders are known globally. Of these, 6479 species under 92 families have been reported from India (ZSI, 2012). Among the known taxa, 2421 species are endemic to India.

THYSANOPTERA

The thrips are unusual insects. They are small and slender-bodied, with or without slender, fringed wings. The last tarsal segment of the legs has an inflatable bladder, which is used to improve the grip of an insect on the substrate. The mouthparts are asymmetrical and of the piercing-sucking form and are used to feed on debris, fungi or plants. Altogether, 6019 species of thrips are known globally, of which 686 species under 258 genera and 7 families have been reported from India. A total of 520 species are endemic to the country.

ENDOPTERYGOTA

MEGALOPTERA

These are commonly known as alder flies and dobsonflies. The larvae of megalopterans are predatory and aquatic, usually living in clear, running water. The adults are medium- to large-sized insects, some of them having enormously enlarged mandibles. So far, 354 species of alder flies and dobsonflies have been reported from around the world. Of these, 25 species under 7 genera and 1 family have been reported from India.

RAPHIDIOPTERA

These are also called snakeflies. The larvae of snakeflies are terrestrial, living on the ground in rotting wood or leaf litter and feeding on smaller insects. So far, 254 species of snakefly have been reported from around the world, and of these 5 species under 2 genera and 1 family have been reported from India.

NEUROPTERA

This group includes lacewings, ant-lions and others. The adults have a greatly elongated prothorax, which gives them a snake-like appearance. Neuropterans are diverse, with a number of forms being elaborate or bizarre. The lacewings are more normal-looking, and the antlions and owlflies are damselfly-like. All are relatively soft-bodied, with large wings that bear elaborately reticulate wing venation. Some adults are known to be predatory, as are most of the immature insects. Immature ant-lions dig conical pits. Their prey falls into these and are grabbed by the waiting larvae. Lacewing larvae prey on aphids and other soft-bodied insects found on foliage. So far, 5868 species of lacewing and ant-lion have been described globally, and of these, 312 species under 112 genera under 12 families have been reported from India.

COLEOPTERA

The beetles represent the greatest proportion of described insect species. More than 1 out of every 4 living organisms is a beetle, and out of the approximately 8,00,000 described species of Insecta, the number of beetle species is 3,59,000 (Arnett *et al.*, 2002; Beutel and Leschen, 2005). This figure has been updated to 3,87,100 species (Zhang, 2011). The Coleoptera are the most successful order of insects in terms of number of species. They are the largest group of organisms in the world. The mesothoracic (first) pair of wings of beetles are greatly strengthened and hardened, such that they are of little or no use in flight but are superb shields when held over the vulnerable abdomen. These hardened forewings, called elytra, are usually held flush over the back of the beetle. The elytra make it slippery and difficult to grasp a beetle, and it is hard and difficult to crush. In many groups, the overall body form is solid, flattened and compact, allowing beetles to hide easily, penetrate cryptic habitats and even burrow extensively in soil. There is no doubt that these modifications have allowed beetles to become the prominent form of insect life on the planet.

Based on estimates including all 169 families of the Coleoptera, more than 3,87,100 species have been described globally and are considered valid. A majority of the species fall under 6 hyper-diverse families (namely the Curculionidae, Staphylinidae, Chrysomelidae, Carabidae, Scarabaeidae and Cerambycidae), each with at least 20,000 species. Differential topography, wide climatic features and varied ecological conditions have contributed to a diversified beetle fauna in India. A part of the fauna has already been worked out and accounts for about 4.86% of all known species of the world, i.e., about 17,455 species belonging to 114 families under 2 suborders, the Adephaga and Polyphaga (ZSI, 2012). Of these, 3100 species are endemic to India.

STREPSIPTERA

These little-known insects are referred to as twisted-winged parasites. These are extremely unusual parasitoids, their hosts being other insects. The adults are highly sexually dimorphic, with the males being free-living, winged insects, whereas the females in all but one family are endoparasitoids—wingless, legless and with only vestigial eyes and appendages on the head. The body of the female extrudes from the body wall of the host, emitting pheromones to attract males that copulate with special openings (external genitalia being absent). So far, 609 species pertaining to 41 genera and 9 families are known globally, of which only 21 species in 8 genera and 4 families are known from India (ZSI, 2012). Of these, 15 species are endemic.

MECOPTERA

These insects are commonly known as scorpion-flies and hanging-flies. The males carry the terminal abdominal segments upturned in the manner of scorpions. Most are terrestrial. The larvae are scavengers, and the adults are scavengers or predators, preying on small insects. The adults and larvae of the unusual brachypterous family Boreidae feed on mosses, whereas the adults of one genus of the Panorpodidae are herbivorous. One family, Nannochoristidae, has aquatic immature forms that feed on larval chironomid midges. Some species have elaborate courtship behaviours involving the presentation of nuptial gifts of dead insects to the female. There are 757 species known from all over the world, representing 9 families. Of these, 23 species belong to two genera, Bittacus and Neopanorpa, are reported from India (Rust and Byers, 1976). Twenty of these species are endemic to India (ZSI, 2012).

SIPHONAPTERA

Fleas are highly modified, laterally flattened, wingless blood feeders. Their hosts are birds and mammals. Usually they are found in the nests of or other areas frequented by their hosts. The larvae are usually free living, feeding on organic detritus and blood in the droppings of the adults, although some are obligate ectoparasites. The adults are extremely laterally flattened and thus able to travel smoothly between the hairs or feathers of their hosts. Often they have backward-jumping legs that allow them to leap to and from their hosts. So far 2075 species of flea belonging to 151 genera in 18 families have been reported globally. In India, this is the least worked out group, and so far there are only 46 species belonging to 24 genera in 8 families (ZSI, 2012). Of these 15 species are endemic to India.

DIPTERA

These are the true flies and are found nearly everywhere. Their distinctive feature is the reduction of the metathoracic wings to a pair of knob-like halteres that act as gyroscopes in flight. This modification has increased their maneuverability and allowed the Diptera to become unparalleled masters of aerial locomotion. Although some adult flies require extensive protein meals to produce mature eggs and to fly, most of the feeding is done by larvae, which can be predators, scavengers, herbivores, parasitoids and even true parasites. Free-living Diptera larvae are found in soil and rotting vegetation, feeding on plants, sometimes exposed on vegetation. Aquatic forms are found in the silt or sand underlying a body of water (sometimes interstitially), on the surface of rocks, logs or vegetation, or in water columns. Parasitoids attack mostly other arthropods, but some endo-parasites attack mammals. The extant Diptera of the world include 1,59,294 species belonging to 159 families. In India, presently 6337 species of true fly belonging to 1180 genera and 87 families are known, including 110 endemic genera and 2183 endemic species endemic.

LEPIDOPTERA

This order includes butterflies and moths. They are among the best-known insects, especially the colorful, diurnal group called butterflies. Most of the diversity of the group, however, is in the nocturnal, often drably colored, moths, which constitute about 80% of the species of Lepidoptera. The larvae are usually called caterpillars and are best known as voracious feeders on plants. Larval feeding takes place on the surface of the plant or within it (as in leaf miners and stem borers), and almost every plant part—leaf, stem, root, flower and seed—can be affected. Some species are also predatory, and some feed on animal material, such as wool, but almost all species are phytophagous. Adults of most families have mouthparts that are modified to form long, coiled tubes that are used for taking up liquids, usually nectar from flowers. About 15,000 species of moth and butterfly belonging to 84 families are known from India (ZSI, 2012), including 1641 species and subspecies of butterfly (Varshney, 2006). Among the known taxa, about 1500 species are endemic to India, mainly butterflies.

TRICHOPTERA

Caddis-flies are close relatives of the Lepidoptera. Caddis-flies have aquatic larvae that are found in nearly every type of freshwater environment. Most construct cases or shelters from plant material, twigs, stones or sand grains tied together with silk. Some also construct nets to capture debris for food, whereas others are predatory, attacking other aquatic insects. The adults are slender, moth-like insects, often with long, thin antennae. A total of 14,899 caddis-fly species, 610 genera and 46 families are known globally. Of these, 1046 species of caddis-fly belonging to 94 genera and 27 families have been reported from India (ZSI, 2012).

HYMENOPTERA

This order includes bees, wasps, ants, sawflies, *etc*. In general, they possess two pairs of membranous wings, with forewings larger than the hind wings. The forewings and hind wings are held together by small hooks (hamuli), but some species may be wingless. The mouthparts are mandibulate (chewing type). Female hymenopterans usually have a hardened ovipositor that may be modified for sawing, piercing or stinging. The order Hymenoptera is divided into 2 suborders, the Symphyta (sawflies) and the Apocrita. The most primitive families are phytophagous, but a great diversity of parasitoids, predators and plant feeders has evolved from these groups. The parasitoids include some of the smallest known insects, which attack the eggs of their much larger hosts. Other parasitoids attack a variety of immature insects, especially those belonging to other holometabolous groups, and develop as endo- or ecto-parasitoids. Some are obligatory hyper-parasitoids—parasitoids of parasitoids; others oviposit in plant tissue and induce the formation of plant galls, in which the larvae feed. The predatory Hymenoptera attack a wide range of hosts, especially other arthropods, which they often subdue but do not kill with a venomous sting. The larvae of these species have a supply of fresh food to consume when they hatch from an egg laid on the paralyzed prey. Most species hide their prey in some sort of burrow or nest to prevent its being taken by other insects or scavenging animals. Some of these provisioning wasps have moved on to pollen and nectar for food, as with the bees. Sociality has evolved a number of times in the Hymenoptera, with the largest and most complex colonies formed by ants and bees.

A total of 1,16,861 species of Hymenoptera (Sharkey, 2007) have been described from around the world. According to recent expert estimates, more than 12,605 species of Hymenoptera in the 12 superfamilies Proctotrupoidea (6 species), Diaprioidea (139), Platygastroidea (150), Ceraphronoidea (9), Cynipoidea (10), Chalcidoidea (2697), Chrysidoidea (1000), Apoidea (1833), Vespoidea (900), Ichneumonoidea (5500), Stephanoidea (11) and Tenthredinidae (350) are known to have been reported from India (ZSI, 2012).

The current diversity of insects in India as compared with that of the world is presented in Table-1. Of the 39 insect orders known globally, 27 are represented in India. The insect orders Geroptera, Protodonata, Palaeodictyoptera, Mishchopterida, Diaphanopterodea, Paoliida, Caloneurodea, Titanoptera, Grylloblattodea, Mantophasmatodea, Zoraptera, Miomoptera and Glosselytrodea have not yet been reported from India.

Presently, 63,760 species of insect (Hexapoda) in 658 families representing 27 orders and three class are reported from India. Eight orders, *viz.* the *Lepidoptera, Coleoptera, Orthoptera, Diptera, Hemiptera, Odonata, Hymenoptera* and *Thysanoptera*, constitute the bulk (94%) of the insect fauna, while the remaining 21 orders are represented by small numbers (6%) of species. The order Coleoptera has the greatest diversity in terms of families—114 families—followed by *Hemiptera* (92 families), *Diptera* (87 families), *Lepidoptera* (84 families) and *Hymenoptera* (65 families).

Table 1. Major divisions of extant Hexapoda in India

S. No..	Class/order	Common name	Number of species described (world) * (Zhang, 2011)	Species in India** (ZSI, 2012)	Genera	Families
	Subphylum Hexapoda		10,29,741*	63,760		658
	Class Collembola	Springtails	8130	299**	103	19
	Class Protura	Proturans	804*	20**	10	3
	Class Diplura	Diplurans	976*	18**	09	04
	Class Insecta	True insects	10,20,007*	63,423		631
1	Order Archaeog-natha	Jumping bristletails	513*	10**	6	2
2	Order Zygentoma	Silverfish	561*	28**	15	3
3	Order Ephemer-optera	Mayflies	3240*	124**	46	12
4	Order Odonata	Dragonflies and damselflies	5899*	463**	139	19
5	Order Plecoptera	Stoneflies	3788*	116**	25	8
6	Order Orthoptera	Grasshoppers, crickets, katydids, etc.	24,276*	1033	398	21
7	Order Phasmida	Walking-sticks	3029*	144**	41	8
8	Order Dermaptera	Earwigs	1978*	298	75	7
9	Order Embioptera	Web-spinners	464*	31**	5	2
10	Order Blattodea	Cockroaches	7314*	186**	58	12
11	Order Mantodea	Mantids	2400*	174**	72	11
12	Order Isoptera	Termites	2864	271**	52	7
13	Order Psocoptera	Bark and book lice	5720*	105	-	16
14	Order Phthiraptera	Lice	5102*	400	-	8
15	Order Hemiptera	True bugs	1,03,590*	6479**	-	92
16	Order Thysanop-tera	Thrips	6019*	686**	258	7
17	Order Megalop-tera	Alder flies, dobsonflies	354*	25	7	1
18	Order Raphidiop-tera	Snakeflies	254*	5	2	1

19	Order Neuroptera	Lacewings, antlions and others	5868*	312	112	12
20	Order Coleoptera	Beetles	3,87,100*	17,455**	-	114
21	Order Strepsiptera	Twisted-winged parasites	609*	21**	8	4
22	Order Mecoptera	Scorpion-flies	757*	23**	2	2
23	Order Siphonaptera	Fleas	2075*	46	24	8
24	Order Diptera	Flies	1,59,294*	6337	1180	87
25	Order Lepidoptera	Butterflies and moths	1,57,424*	15,000**	-	84
26	Order Trichoptera	Caddis-flies	14,999*	1046**	94	27
27	Order Hymenoptera	Sawflies, ants, bees and wasps	1,16,861*	12,605	65	57

INSECT FAUNA OF STATES AND UNION TERRITORIES OF INDIA

India's insect fauna is distributed over a wide range of ecosystems, climatic regions and altitudes. Publication of the State Fauna Series was started by the Zoological Survey of India in 1987 to make available information on the faunal wealth of all the states and union territories. Twenty states (Odisha, Lakshadweep, West Bengal, Meghalaya, Andhra Pradesh, Tripura, Delhi, Gujarat, Sikkim, Manipur, Bihar, Nagaland, Arunachal Pradesh, Mizoram, Madhya Pradesh, Goa, Tamil Nadu, Uttarakhand, Maharashtra and Andaman and Nicobar Islands) have been covered to date (Editor-Director, 1987-2012). Many groups of insects have been included in the series. The author of the present work has also compiled accounts of the insect biodiversity of the Andaman and Nicobar Islands (Chandra, 1999a), Madhya Pradesh and Chhattisgarh (Chandra, 2004a), Ladakh-Jammu and Kashmir (Chandra and Sidhu, 2009) and Sikkim (Chandra, 2011b). The 50 volumes of the Fauna of British India and 25 volumes of the Fauna of India pertaining to 9 insect orders, namely Odonata (Fraser, 1933, 1934, 1936), Orthoptera (Kirby, 1914; Chopard, 1969), Isoptera (Roonwal and Chhotani, 1989; Chhotani, 1997), Dermaptera (Burr, 1910; Srivastava, 1988, 2003), Hemiptera (Distant, 1902-1918; Ghosh, 1980, 1982, 1984a, 1984b; Ghosh and Quednau, 1990; Ghosh and Agarwala, 1993; Ananthasubramanian, 1996; Ghosh and Ghosh, 2006), Coleoptera (Andrews, 1929, 1935; Arrow, 1910, 1917, 1925, 1931, 1949; Cameron, 1930, 1931, 1932, 1934, 1939a, 1939b; Fowler, 1912; Gahan, 1906; Jacoby, 1908; Vazirani, 1984; Pajni, 1990; Maiti and Saha, 2004, 2009), Diptera (Brunetti, 1912, 1920, 1923; Christophers, 1933; Baraud, 1934; Senior-White *et al*., 1940; Emden, 1965; Joseph and Parui, 1998; Cherian, 2002; Nandi, 2002), Lepidoptera (Hampson, 1892, 1894, 1895, 1896; Bell and Scott, 1937) and Hymenoptera (Bingham, 1897, 1903; Morley, 1913; Mani, 1989a, 1989b; Gupta and Jonathan, 2003) were also referred to in the preparation of the present work. Monographs, special publications, the Conservation Area Series, the Ecosystem Series, Records of the Zoological Survey of India (journal), Occasional Papers and other scattered research papers/articles on insects, including authentic online information, were also consulted to evaluate the insect diversity in all the states and union territories better. Contributions to insect systematic are listed group-wise in Table 2.

Table 2. Selected contributions to insect systematics in India, (by group)

S. No.	Class/order	References
	Subphylum Hexapoda	
	Class Collembola	Mitra (1993); Hazra and Mandal (2007a and b); Mandal (2009); Mandal and Hazra (2009); Janssens (2012)
	Class Protura	Prabhu (1986); Mandal (2010a)
	Class Diplura	Mandal (2010b)
	Class Insecta	
1	Order Archaeognatha	Mandal (2010c)

2	Order Zygentoma	Mendes (1990); Hazra and Mondal (2007a); Mandal (2010c)
3	Order Ephemeroptera	Hubbard and Peters (1978); Sivaramakrishnan et al. (2009)
4	Order Odonata	Fraser (1918-1919); Prasad and Varshney (1995); Mitra (1994, 1999, 2002a, 2002b, 2006); Mitra and Babu (2010); Uniyal et al. (2000); Emiliyamma et al. (2006, 2007); Mitra and Mitra (2009).
5	Order Plecoptera	Das (2008).
6	Order Orthoptera	Kirby (1914); Uvarov (1927); Chopard (1969); Bhowmik (1985a, 1985b); Vasanth (1993); Shishodia (1991); Shisodia et al. (2010)
7	Order Phasmida	Mandal and Yadav (2010)
8	Order Dermaptera	Burr (1910); Srivastava (1988)
9	Order: Embioptera	Kapur and Kripalani (1957)
10	Order Blattodea	Mandal,S.K. (2008)
11	Order Mantodea	Mukherjee et al. (1995); Vyjayandi (2007); Sureshan (2009)
12	Order Isoptera	Maiti (1983); Bose (1984, 1999); Roonwal and Chhotani (1989); Maiti and Chakraborty (1994); Chhotani (1997); Rathore and Bhattacharya (2004)
13	Order Psocoptera	New (1977)
14	Order Phthiraptera	Lakshminarayana (1979, 1982a, 1982b, 1986); Adhikary and Ghosh (1994)
15	Order Hemiptera	Distant (1902-1918); Mathur (1975); Varshney (1976, 1992, 2002); Basu (1981 (1982)); Datta et al. (1985); Ghosh and Dhar (1985); Kandasamy (1985); Datta (1988); Mukhopadhyay (1988); Viraktamath and Wesley (1988); Thirumalai (1989, 1994, 2007); Rao (1990); Chakraborty et al. (1994); Hegde (1994); Ananthasubramanian (1996); Viraktamath (1998); Ambrose (2003); Jesudasan (2003)
16	Order Thysanoptera	Ananthakrishnan and Sen (1980); Sen, Pramanik and Sengupta (1986); Sen (1994)
19	Order Neuroptera	Ghosh (1984, 2000).
20	Order Coleoptera	Gahan (1906); Jacoby (1908); Arrow (1910, 1917, 1925, 1931, 1949); Fowler (1912); Marshall (1916); Maulik (1919, 1926, 1936); Andrews (1929, 1935); Cameron (1930, 1931, 1932, 1937); Balthasar (1963a and b, 1964); Vazirani (1977, 1984); Pal (1985, 2004); Maiti and Saha (1986); Ramamurthy and Ghai (1988); Sengupta (1988); Uniyal and Vats (1988); Uniyal et al. (1989); Supare et al. (1990); Saha et al. (1992); Sengupta and Pal (1996); Poorani and Ramamurthy (1997); Chandra (1999b); Uniyal and Mathur (2000); Chakraborty and Chakraborty (2001); Poorani (2002); Maiti and Saha (2004); Uniyal and Bhargav (2007b); Bhargav et al. (2009).
21	Order Strepsiptera	Kathirithamby (1989)
22	Order Mecoptera	Prasad (1998); Penny and Byers (1979); Chandra (2004b)
23	Order Siphonaptera	Iyenger (1973); Adhikari and Ghosh (1994)
24	Order Diptera	Brunetti (1912, 1920, 1923); Christophers (1933); Datta (1983); Barraud (1934); Emden (1965); Senior-White et al. (1940); Delfinado and Hardy (1973, 1975, 1977); Singh and Ipe (1973); Joseph and Parui (1983, 1984, 1990, 1998); Alfred and Dasgupta (1992); Cherian (2002); Nandi (2002, 2004); Parui et al. (2004); Banerjee and Mitra (2006); Mitra et al. (2008, 2010)
25	Order Lepidoptera	Marshall and De Niceville (1882); De Niceville (1886, 1890); Cotes and Swinhoe (1887-1889); Hampson (1892, 1894, 1895, 1896, 1908, 1912, 1917, 1919, 1930); Evans (1932); Bell and Scott (1937); Talbot (1939, 1947); Wynter-Blyth (1957); Arora (1976 and 1983); Arora and Gupta (1979); Holloway (1984); Gupta and Shukla (1987, 1988); Gupta (1994); Smetacek (1994); Uniyal and Mathur (1998); Varshney (2006); Uniyal (2007); Uniyal and Bhargav (2007a); Kumar (2008); Arora et al. (2010); Bhardwaj and Uniyal (2012); Sanyal et al. (2013)

26	Order Trichoptera	Heigler (1992)
27	Order Hymenoptera	Bingham (1897, 1903); Morley (1913); Hammer (1960); Hayat (1974); Boucek and Subba Rao (1978); Mani (1989a, 1989b); Mani and Sharma (1982); Mukherjee (1994); Tiwari (1999); Sureshan (2003, 2007, 2009); Gupta (2004); Sureshan and Narendran (2004); Narendran and Sudheer (2005); Narendran (2007); Rajamohana (2007); Priyadarsanan (2000); Tak (2008)
28	Miscellaneous	Maxwell-Lefroy (1909); Stebbing (1914); Beeson (1941); Menon (1965); Champion and Seth (1968); Anon (1980, 1991, 2013); Ghosh (1996, 1992-2001); Varshney (1997, 1998); Ananthakrishnan (2000); Mathew and Binoy (2003); Chandra and Rajan (2004); Chandra (2007a, 2007b, 2009a, 2009b, 2011a); Chakravarthy et al. (2008); Alder Peter and Foottit (2009); Chandra and Sidhu (2009); Chandra et al. (2010); Ramakrishna et al. (2010); Sanyal and Alfred (2011); Zhang (2011)

Map 1. Insect fauna of states and union territories in India.

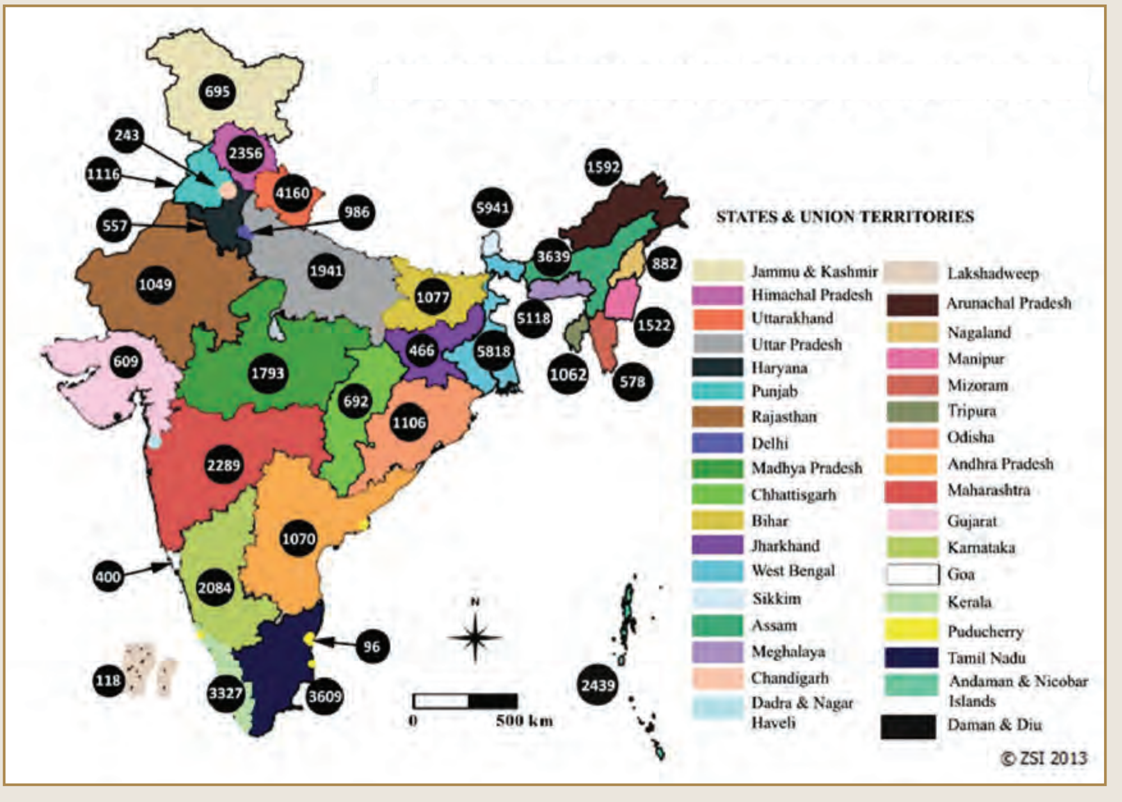

Table 3. Insect fauna of states and union territories, by group

Taxon	Andman and Nicobar Islands	Andhra Pradesh	Arunachal Pradesh	Assam	Bihar	Chandigarh	Chhattisgarh	Delhi	Goa	Gujarat	Haryana	Himachal Pradesh	Jammu & Kashmir	Jharkhand	Karnataka	Kerala	Lakshadweep	Madhya Pradesh	Maharashtra	Manipur	Meghalaya	Mizoram	Nagaland	Odisha	Puducherry	Punjab	Rajasthan	Sikkim	Tamil Nadu	Tripura	Uttarakhand	Uttar Pradesh	West Bengal
Collembola	18	22	27	20								21	15	10		60		27	24	27	11	21	18	21			6	39	24	11	31	35	25
Protura																20																	1
Diplura													1			5			8										4				1
Archaeognatha	2	1										10	4			2													5		1	1	
Zygentoma	1	6						3				5	2						8	3							2	3	5	2	4	4	9
Ephemeroptera	1	1		4	3							25	8	1	5	5		12	19	6	5			5				2	24	5	1	3	17
Odonata	72	68	92	65	63	8	52	47	39	58	17	86	23	109	137	137		90	101	68	151	64	48	58		36	48	45	135	35	122	69	185
Dermaptera	14	3	80	18	5		6	4				30	14		32	19	3	16	13	28	49	15	3	14	4	3	3	50	75	14	36	12	79
Plecoptera				30								20	2		3	6		1	1	8	16					1		6	12			8	21
Embioptera	2	1		3							1				7	4		2			2							6	7		2		8
Orthoptera	85	84	149	221	123	36	81	94	37	22	30	165	77	14	155	129	10	121	146	120	161	94	46	146	19	52	87	123	341	108	144	100	278
Phasmida	4		4	21	3								1		3	6		1	1		11		8					16	20				28
Mantodea	7	13	20	29	14		3		9			20	4	10	23	14	1	31	56	10	25			27			9	17	35	2		55	35
Blattaria	12	14	20	5				9				1			2	2	4	10	12	8	26			12	4		4	17	47	10			23
Isoptera	40	12	44	26	9		6	14	5	60	8	12	16	18	47	56		35	17	22	31	15	11	31		9	61	16	46	27	47	28	55
Psocoptera				22									2			36			14	7	6			1						5			39
Phthiraptera	4	15		16	5		1	6		4	3	20	22		2	6		7	11	18	4		1	1		41	39	35	3		8	28	35
Thysanoptera	29	77	9	24	11	8		116	9	7	17	31	21		145	141		81	63	26	49	1	3	8		45	20	17	321	35	31	88	124
Coleoptera	580	137	73	810	156	17	250	102	4	126	280	205	99	52	144	302	9	355	420	325	911	50	45	198	21	296	239	994	750	283	1074	210	1570
Neuroptera	13	4	9	34	37		24		2			15	10		36	5		33	74	7	45	10		23	1	12	5	36	23	4		13	79
Mecoptera				3			1			1		2			1	3	1	1	2						1			4	7		1		3
Siphonaptera	2			3						1	2	5	8		9	4		2	7	2						2		6	11		1	8	13
Strepsiptera			2		1										2														1				14
Diptera	303	71	272	589	146	72	25	79	7	106		417	135		164	342	3	257	386	92	321	71	69	39		109	135	634	464	119	541	93	681
Lepidoptera	804	153	494	980	250	80	193	111	251	150	124	570	107	209	318	529	84	475	253	269	1775	145	493	141		340	216	2528	319	135	1523	190	1020
Trichoptera	20	4	160	129	36			1				5	22		53	40		24	43	131	158	16		7		24		179	65			154	79
Hymenoptera	176	201	117	227	180	3	20	248	32	62	61	319	83	43	669	997	3	77	339	52	754	7	7	199	31	102	116	619	612	61	181	806	430
Total	2439	1070	1592	3639	1077	243	692	986	400	609	557	2356	695	466	2084	3327	118	1793	2289	1522	5118	578	882	1106	96	1116	1049	5941	3609	1062	4160	1941	5818

DISCUSSION

The insect distribution is mainly influenced by the ecological, climatic and edaphic factors, such as the vegetation, rainfall and temperature. The insect fauna in the Himalayan Zone, including the mountains in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, north-west Bengal, Meghalaya and Arunachal Pradesh, is influenced by the Palaearctic elements. However, the insect fauna of the desert areas of Rajasthan, Gujarat and Ladakh (cold desert) varies due to variation in extreme temperature in these states. The tropical humid forests of the Western Ghats and the eastern Himalaya are different from the island ecosystems of the Andaman and Nicobar Islands, but the greatest numbers of endemic species occur in these ecosystems.

The present account is a compilation of the information available in about 5000 references. Despite non-uniformity across states and taxa in the available information, certain trends are visible. These trends permit us to infer both gaps in our knowledge and survey the insect fauna of the various states and union territories. It is evident that the insect diversity of Sikkim (5941) is the greatest, followed by those of West Bengal (5818), Meghalaya (5118) and Uttarakhand (4160). All these states are quite well explored, but many more species are expected, possibly up to 15,000 species. The number of species ranges from 2000 to 4000 in the states of Kerala (3327), Tamil Nadu (3609), Karnataka (2084), Maharashtra (2289), Himachal Pradesh (2356), Assam (3639) and the Andaman and Nicobar Islands (2439), and the biodiversity hotspots in India fall in them. These areas are still under-explored, and the diversity therein is expected reach up to 10,000 species. Andhra Pradesh (1070 species), Arunachal Pradesh (1592), Bihar (1077), Madhya Pradesh (1793), Manipur (1522), Odisha (1106), Punjab (1116), Rajasthan (1049), Tripura (1062) and Uttar Pradesh (1941) have 1000 to 2000 species. These states are also under-explored, and their insect diversity is expected to include more than 6000 species. The states of Chhattisgarh, Delhi, Gujarat, Jammu and Kashmir, Haryana, Jharkhand, Mizoram and Nagaland are the least explored, and fewer than 1000 species have been reported from each of them, and the number of species may be up to 4000 species. Fewer than 500 species have been reported from the union territories, namely Chandigarh, Lakshadweep and Puducherry, and the state of Goa. They are almost unexplored, and more than 2000 species may be found if intensive surveys are undertaken (Tables–4 & 5). Very few species (fewer than 100) have been reported so far from Dadra and Nagar Haveli, Daman and Diu. These union territories are not included in the present account.

The numbers of species known to occur in the states and union territories are shown in Map-1. The areas and numbers of species are compared in Table-4 and Figure-1. It is evident from the data in Table-4 that the level of faunal exploration in the various states and union territories varies from 5% to 60%. There is a need to prioritize the areas and the groups to be surveyed so that a better understanding of the the biodiversity is obtained. Moreover, the resources utilized for studying common groups such as butterflies may be reduced, since lesser known groups are neglected. There are some groups, such as Protura, Diplura, Plecoptera, Embioptera, Psocoptera, Phthiraptera, Strepsiptera, Mecoptera and Siphonaptera, that have not been dealt with at all in the last few decades.

The tropical evergreen forests of the eastern Himalaya and the hills of north-east India including the states of Sikkim, Meghalaya, Arunachal Pradesh, Manipur, Nagaland, Tripura and Mizoram and north-west Bengal harbour the greatest number of insect species, followed by the states in which the Western Ghats fall, such as Kerala, Tamil Nadu, Karnataka and Maharashtra. The third biodiversity-rich areas in terms of insects are the western Himalayan region and the Andaman and Nicobar Islands.

There are still many inaccessible areas in the country that have not been adequately explored for assessment of the insect wealth. In some cases, information relating to a particular group of insects is available from only one or a few states. The present study may yield information on not only gap areas at the macro level for all the states and union territories but also gaps relating to taxa at the micro level. This information will help obtain a holistic view of insect biodiversity so that biodiversity may be monitored at various levels across regions and periods.

Table 4. Comparison of area, forest cover and insect fauna in states and union territories

S. No.	States and Union Territories	Total Area (Sq. Km.)	Percentage of the total area of country	Total Forest Cover (Sq. Km)	Percentage of forest cover	Total No. of insect species known	Percentage of Insect diversity	Insect fauna explored (%)
1	Andaman & Nicobar Islands	8249	0.2509	6964	84.42	2439	3.83	50

2	Andhra Pradesh	275069	8.3677	44419	16.15	1070	1.68	20
3	Arunachal Pradesh	83743	2.5475	68019	81.22	1592	2.50	20
4	Assam	78438	2.3861	27826	35.48	3639	5.71	40
5	Bihar	94163	2.8645	5558	5.90	1077	1.69	20
6	Chandigarh	114	0.0035	15	13.16	243	0.38	40
7	Chhattisgarh	135191	4.1126	55998	41.42	692	1.09	20
8	Delhi	1483	0.0451	170	11.46	986	1.55	40
9	Goa	3702	0.1126	2156	58.24	400	0.63	20
10	Gujarat	196022	5.9631	14946	7.62	609	0.96	10
11	Haryana	44212	1.3449	1517	3.43	557	0.87	20
12	Himachal Pradesh	55673	1.6936	14353	25.78	2356	3.70	40
13	Jammu & Kashmir	222236	6.7605	21267	9.57	695	1.09	20
14	Jharkhand	79714	2.4249	22716	28.50	466	0.73	10
15	Karnataka	191791	5.8344	36449	19.00	2084	3.27	40
16	Kerala	38863	1.1822	15577	40.08	3327	5.22	50
17	Lakshadweep	32	0.0010	23	71.88	118	0.19	10
18	Madhya Pradesh	308245	9.3769	76429	24.79	1793	2.81	30
19	Maharashtra	307713	9.3608	46865	15.23	2289	3.59	30
20	Manipur	22327	0.6792	17219	77.12	1522	2.39	50
21	Meghalaya	22429	0.6823	16839	75.08	5118	8.03	60
22	Mizoram	21081	0.6413	18430	87.42	578	0.91	10
23	Nagaland	16579	0.5043	13609	82.09	882	1.38	20
24	Odissa	155707	4.7367	48366	31.06	1106	1.73	30
25	Puducherry	480	0.0146	40	8.33	96	0.15	30
26	Punjab	50362	1.5320	1580	3.14	1116	1.75	30
27	Rajasthan	342239	10.4111	15826	4.62	1049	1.65	30
28	Sikkim	7096	0.2159	3262	45.97	5941	9.32	60
29	Tamil Nadu	130058	3.9564	22643	17.41	3609	5.66	40
30	Tripura	10486	0.3190	8093	77.18	1062	1.67	30
31	Uttarakhand	53483	1.6270	24465	45.74	4160	6.52	50
32	Uttar Pradesh	240928	7.3291	14118	5.86	1941	3.04	20
33	West Bengal	88752	2.6999	12343	13.91	5818	9.12	60
		3,28,7263		6,78,333		63,760		

Table 5. Estimates of insect diversity of states and union territories

S. no.	States and union territories	Number of insect species known	Status of exploration	Status	Estimate of number of species
1	Sikkim, West Bengal, Meghalaya, Uttarakhand	4000 to 6000	Quite well explored	Very rich diversity	>15,000
2	Assam, Kerala, Tamil Nadu, Andaman and Nicobar Islands, Himachal Pradesh, Karnataka, Maharashtra	2000 to 4000	Under-explored	Rich diversity	>10,000

3	Andhra Pradesh, Arunachal Pradesh, Bihar, Madhya Pradesh, Manipur, Odisha, Punjab, Rajasthan, Tripura, Uttar Pradesh	1000 to 2000	Under-explored	Moderate diversity	>6000
4	Chhattisgarh, Delhi, Gujarat, Jammu and Kashmir, Haryana, Jharkhand, Mizoram, Nagaland	500 to 1000	Least explored	Poor diversity	>4000
5	Chandigarh, Dadra and Nagar Haveli, Daman and Diu, Goa, Lakshadweep, Puducherry	0 to 500	Unexplored	Very poor diversity	>2000

ENDEMISM IN INSECT FAUNA OF INDIA

Insect diversity in India is characterized by a high level of endemism. The diversity of insects is greater in the north-eastern states, the Western Ghats and the Andaman and Nicobar Islands, and these areas also have a high level of endemism. A high percentage of endemism is noted in the primitive insect groups, viz., Protura (85%), Diplura (66%) and Thysanura (60%), followed by Collembola (15 %). Among the exopterygotes, Thysanoptera has the highest percentage of endemism (75%), followed by Phasmida (68%), Ephemeroptera (58%), Plecoptera (57%), Orthoptera (54%), Embioptera (45%) and Isoptera (44%), and there is less than 40% endemism in the remaining orders. Among the endopterygotes, the endemism in species level is the highest in Mecoptera (86%), followed by Neuroptera (76%), Strepsiptera (71%), Hymenoptera(71%), Trichoptera (60%), Diptera (35%) and Coleoptera (17 %), while the order Lepidoptera shows only 10% endemism since the moth fauna is widely distributed in the Indo-Pacific region (Table 6).

Table 6. Numbers of endemic genera and species of insect in India

	Class/order	Number of species known in India	Endemic genera	Endemic species	Percentage of species endemic to India
A	Class Collembola	299	22	45	15.05
B	Class Protura	20	4	17	85.00
C	Class Diplura	18	3	12	66.66
D	Class Insecta				
1	Order Thysanura	38	12	23	60.52
2	Order Ephemeroptera	124	-	72	58.06
3	Order Odonata	463	6	115	24.83
4	Order Plecoptera	116	-	66	56.89
5	Order Orthoptera	1033	77	563	54.50
6	Order Phasmida	144	-	99*	68.75
7	Order Dermaptera	298	3	117	39.26
8	Order Embioptera	31	-	14	45.16
9	Order Blattodea	186	14	60	32.25
10	Order Mantodea	174	24	77*	32.25
11	Order Isoptera	271	-	172*	44.25
12	Order Psocoptera	105	-	15	14.28
13	Order Phthiraptera	400	-	16	04.00
14	Order Hemiptera	6479	579	2421	37.36

15	Order Thysanoptera	686	92	520	75.80
16	Order Neuroptera	342	13	262	76.60
17	Order Coleoptera	17,455	923	3100	17.75
18	Order Strepsiptera	21	-	15	71.42
19	Order Mecoptera	23	-	20*	86.95
20	Order Siphonaptera	46	-	15	32.60
21	Order Diptera	6337	107	2183*	35.06
22	Order Lepidoptera	15,000	100	1500	10.00
23	Order Trichoptera	1046	5	650	62.14
24	Order Hymenoptera	12,605	516	9000	71.40
	Total	63,760		21,166	33.40

All data other than those indicated with asterisks are from Varshney (1998).

THREATS AND CONSERVATION

Threats: Changes in habitats all across the country, particularly in fragile ecosystems such as freshwater ecosystems and forests areas, has also impacted the insect diversity of India. Pollution of streams, particularly through drainage and siltation, has resulted in profound changes in aquatic insect communities. The conservation of natural habitats for agricultural purposes, particularly for cultivation of cash crops, has resulted in a great loss of native insect populations. The introduction of exotic insects for the control of pests or weeds directly or indirectly affects the population of native insects. However, the major factor responsible for the loss of insect populations during the last few decades is the widespread use of organic pesticides.

CONSERVATION

There are certain creative approaches needed for the conservation of insect diversity. First and foremost is the maintenance and conservation of natural reserves which are about 5% under the protected area network. There are many specialist species that migrate to specific habitats found in reserves of a particular size. With a reduction in the extent of a habitat in a transformed landscape, population declines or species extinctions may follow. There is a need to maintain as much natural diversity as possible at various spatial levels in a heterogeneous landscape. This will afford opportunities for maximal growth of indigenous species of plant to support endemic species and suppress invasive species. Landscapes must be maintained undisturbed or at a minimal level of disturbance to protect larger assemblages of species and to permit their migration. Small natural patches also have important conservation value for certain insect species and may act as stepping stone habitats for some species. The corridors, which are continuous strips of habitats between large, similar landscapes, are to be established to improve the chances of survival of isolated populations. Various studies have illustrated how insects move along the corridors of natural landscapes. The insect fauna migrates from one region to another, and the population is maintained.

THREATENED SPECIES

The degradation of sensitive and fragile ecosystems, especially forest and freshwater areas, has caused concern among environmentalist and conservation biologists. A total of 99 national parks, 513 wildlife sanctuaries, 41 conservation reserves and 4 community reserves have been notified (Anon, 2008). The Indian Wildlife (Protection) Act, 1972 lists a total of 493 species of insect, including 454 species of Lepidoptera, 38 species of Coleoptera and 1 species of Odonata in 3 Schedules namely I, II and IV (Sharma and Ramamurthy, 2010). Details are provided family-wise in Table–7.

Table 7. Numbers of threatened insect species in India

S. no.	Schedule	Order	Family	Total number of species/ subspecies
1.	Schedule I, Part IV	Lepidoptera		128 species
			Amathusiidae	3
			Danaidae	3
			Lycaenidae	47

			Nymphalidae	37
			Papilionidae	14
			Pieridae	6
			Satyridae	18
		Odonata	Epiophlebiidae	1
2.	Schedule II, Part II	Lepidoptera		307
			Amathusiidae	10
			Danaidae	2
			Erycinidae	1
			Hesperidae	3
			Lycaenidae	116
			Nymphalidae	173
			Papilionidae	21
			Pieridae	21
			Satyridae	156
		Coleoptera		38
			Carabidae	13
			Chrysomelidae	16
			Cucujidae	8
			Inopeplidae	1
3.	Schedule IV, Part IV	Lepidoptera		19
			Danaidae	4
			Hesperidae	9
			Lycaenidae	1
			Nymphalidae	1
			Pieridae	4

The relict Himalayan dragonfly species of Anisozygoptera, Epiophlebia laidlawi, occurring in isolated hill streams in Darjeeling is a great taxonomic curiosity. This species has characters that link the two suborders of the Odonata, namely Zygoptera and Anisoptera, and is protected under the Wildlife (Protection) Act, 1972.

Detailed population studies have not been carried out on many groups of insects. As a result, the distribution ranges of the majority of insects are not yet clearly known. Hence, many species whose populations may be declining and which may be rare are not listed in the threatened category. Documentation of biodiversity is the prerequisite for appropriate conservation strategies, as has been highlighted at the Convention of Biological Diversity (CBD), held in 1992. Taxonomists are at the crossroads since they have no incentive to take up taxonomic studies. With further environmental degradation and increasing deforestation, several taxa of insects will be endangered soon if they are not protected. Many species will become extinct before they are made known to the world.

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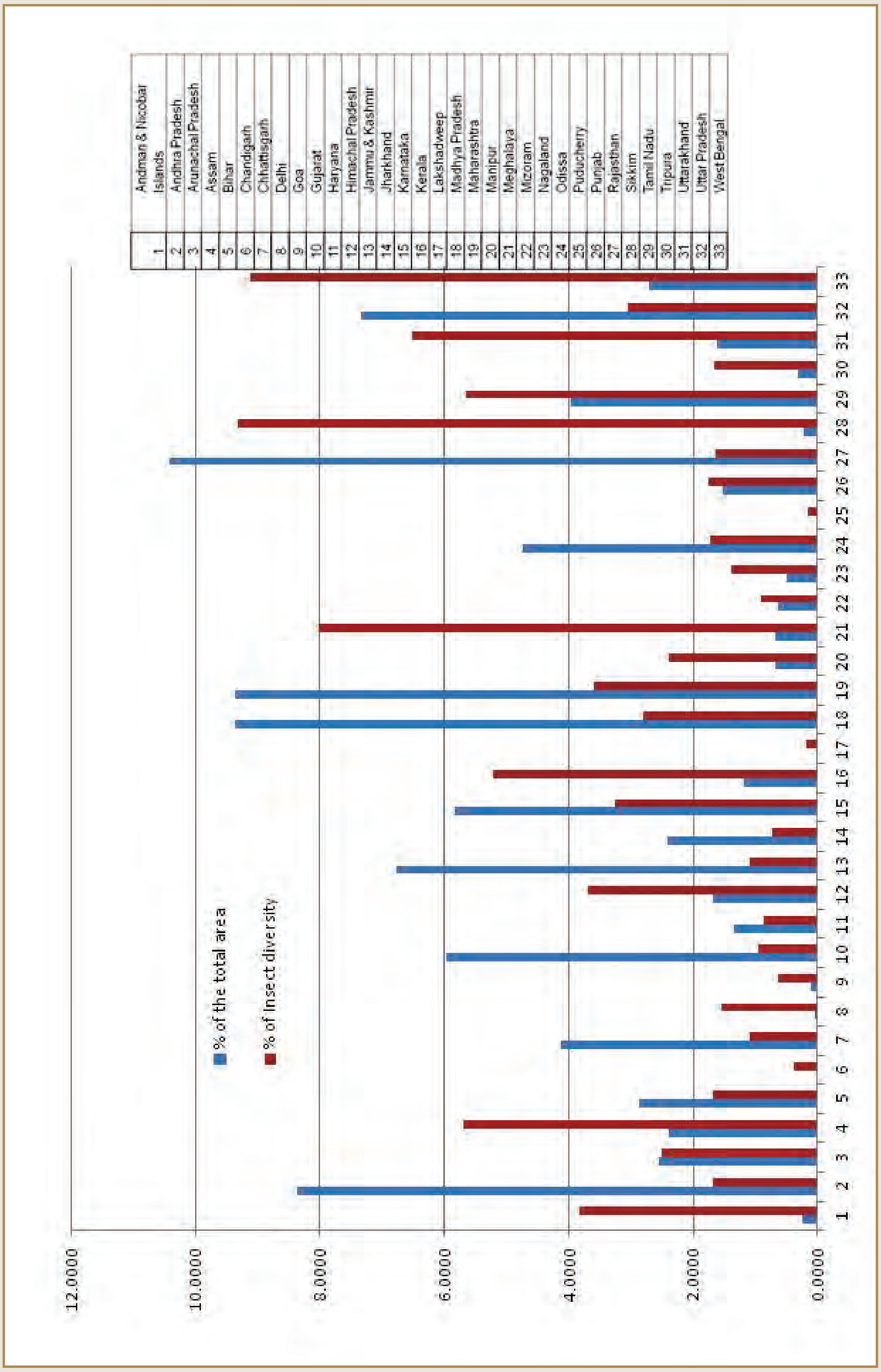
Figure 1.

Comparison of area and insect diversity in states and union territories of India



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SPIDER DIVERSITY ALONG ALTITUDINAL GRADIENT AND ASSOCIATED CHANGES IN MICROCLIMATE ATTRIBUTES IN NANDA DEVI BIOSPHERE RESERVE, UTTARAKHAND, INDIA

Shazia Quasin and V. P. Uniyal
Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand, India
email: uniyalvp@wii.gov.in

INTRODUCTION

Global species diversity patterns are likely to change across spatial gradients in response to changes in climate, area, latitude, altitude, productivity, available resources and habitat complexity (MacArthur, 1972; Rosenzweig, 1995; Trevelyan and Pagel, 1995). As altitudinal gradients are usually characterized by rapid environmental changes over short horizontal distances, they are thus known to be ideal for investigating diversity patterns (Hodkinson, 2005). The patterns of species diversity of invertebrates along the elevation gradient have long been a contentious topic. The two general patterns that emerge are a monotonic decrease in species richness with increasing elevation (MacArthur, 1972; Stevens, 1992) and a hump-shaped relationship, with a peak at intermediate elevations (Rahbek, 1995). Studies have been conducted on several taxa along elevation gradients that reveal that there is a large variation in diversity patterns. Both patterns have been documented in a variety of habitats and taxa (Terborgh, 1977; Stevens, 1992; Brown, 1995; Rahbek, 1995; Rosenzweig, 1995). However, the two most commonly observed patterns of species richness along altitudinal gradients are a steady decline in diversity with increasing elevation and a unimodal pattern (Nogués-Bravo *et al*., 2008). It is observed that diversity generally decreases at higher elevations in plants (Hamilton and Perrott, 1981; Kessler, 2001; Hemp, 2002) and animals (Rahbeck, 1995).

The negative effect of altitude (Stevens, 1992; Brown *et al.*, 1996) is explained as a consequence of the wider ecological forebearance of organisms at higher elevations. It is a crucial characteristic that has to be possessed in order to withstand the wider climatic fluctuations to which they are exposed. The effect of elevation on species richness can be attributed to the following reasons: (i) reduction in productivity with elevation; (ii) reduction in total area; (iii) reduction in resource diversity; and (iv) harshness and unpredictability of the conditions prevailing at higher elevations (Lawton *et al.*, 1987). Colwell and Lees (2000) have suggested the mid domain effect, i.e. the peak in species richness at mid elevations, due to the increasing overlap of species ranges towards the centre of a domain or minor peaks at transitions between elevational communities, to be very robust among different taxa. Another phenomenon associated with negative effect of altitude is the 'rescue effect' i.e. the reduced likelihood of a population at higher elevations to be rescued by individuals dispersing from other zones, compared with populations at lower elevations (Brown and Kodric-Brown, 1977). Thus, it could be that the species richness is overblown in lower altitudes by the emigration of high-altitude species at the margins of their ranges due to wider tolerance, while taxa from lower elevations cannot expand their upper limit of elevation range as immigration rates also decrease with elevation (Stevens, 1992).

For insects, the empirical evidence for both peaks in species richness at low elevations (Wolda, 1987; Fernandes and Price, 1988; McCoy, 1990; Kearns, 1992; Stevens, 1992; Olson, 1994; Sparrow 1994) and peaks in species richness at intermediate elevations has been established through several studies (Janzen, 1973; McCoy, 1990; Olson, 1994; Sanchez-Rodriguez and Baz, 1995; Fleishman *et al.,* 1998; Sanders, 2002). Most studies have revealed a hump-shaped distribution (Holloway *et al.*, 1990; McCoy, 1990; Olson, 1994; Holloway, 1997; Pyrcz and Wojtusiak, 2002), whereas Wolda (1987) found a general decrease with increasing elevation. Although several invertebrate groups have been studied across altitudinal gradients, for example, butterflies, moths, ants, dragonflies and beetles, only few studies have been conducted so far on spiders in the Indian subcontinent. *Waide et al.* (1999) considered spiders as model taxa for investigating the effects of spatial gradients on species assemblages on a scale of 200-4000 km. As they are ubiquitous, abundant, easily collectible and sensitive towards fine-scale environmental changes, they can be used to reflect ecological change. Thus, they easily respond to changes in habitat heterogeneity *(Downie et al.,* 1995), temperature and humidity (*DeVito et al*., 2004), as a result of which species assemblage patterns may be assessed at a regional scale. Chatzaki *et al.* (2005) found that the species richness of ground-dwelling spiders (Gnaphosidae) followed a hump-shaped pattern in Crete, Greece. Maurer and Hänggi (1991), who studied the altitudinal variation of spider species in Switzerland, reported a more or less linear decline and an abrupt decrease in the number of species above the timberline. An ecological survey of ground spiders along altitudinal gradients in Norway (Otto and Svensson, 1982) found the same pattern of species decline with altitude from 0 to 800 m.

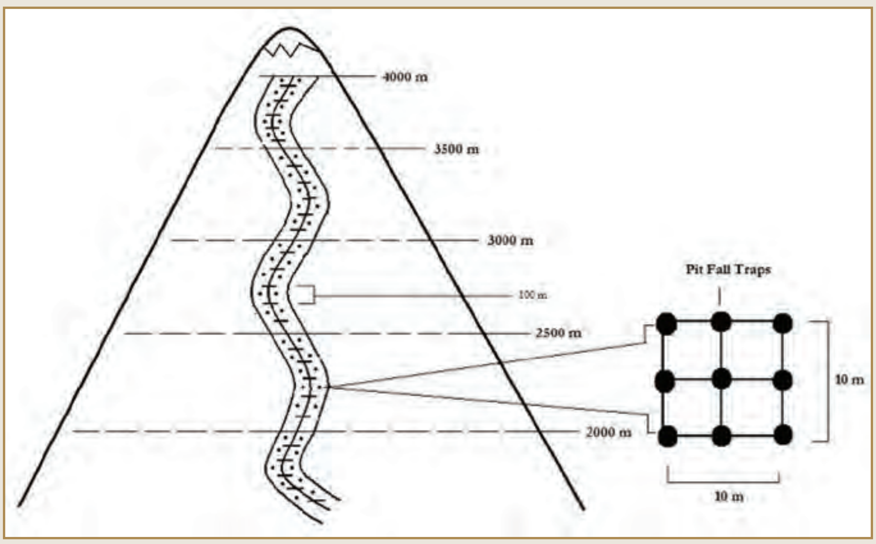
This study intended to describe the species diversity patterns along the three altitudinal gradients (sites) of the Nanda Devi Biosphere Reserve (NDBR). The objectives of the study were (1) to describe the regional species diversity and composition, (2) to inspect if the species composition changes along the altitudinal gradient and (3) to examine the altitudinal patterns of species diversity. With these objectives, the following research questions were raised: (i) Is there a general trend of altitudinal species diversity, or does it vary between sites? (ii) What is the most parsimonious yet robust species diversity pattern? (iii) Are these altitudinal trends of diversity similar between guilds? The three alternative hypotheses that were tested were the following: (a) the altitudinal species diversity pattern follows a general trend at the regional scale; (b) the altitudinal species diversity pattern follows similar trends in the region but with random site effects; and (c) the altitudinal species diversity pattern differs between sites. Further, (d) whether this altitudinal diversity is linearly declining or unimodal was tested. As spiders are also adapted to a rather narrow set of abiotic factors such as temperature, humidity and pH, (e) whether these factors influence local diversity was also tested.

METHODS

SPIDER SAMPLING

Selected sites with substantial altitudinal ranges were sampled in the NDBR. As spiders are diverse in their ways of life, in order to collect them from all habitats, the sampling needed a combination of methods. So we used six different collection techniques, *viz.*, pitfall trapping, vegetation beating, litter sampling, ground hand collection, aerial hand collection and sweep netting (*Coddington et al.*, 1996). Nine pitfall traps (cylindrical plastic bottles of diameter 9 cm and depth 11 cm, mainly for collecting ground-dwelling spiders) were arranged within the quadrates in three horizontal rows and three vertical rows, each at a distance of 5 m from the nearest neighbour, thus forming four smaller grids of 5 m × 5 m within the sampling plot (Figure

Figure 1.



Sampling design

1). The traps were filled with liquid preservative (69% water, 30% ethyl acetate and 1% detergent). Other methods were used to collect web builders, ambushers, and ground-running spiders. Specimens were identified up to the family, genus and species levels when possible. Sampling was carried along the gradient in three sites: Lata Kharak (Site 1, 2000-4000 m); Bhyundar Valley (Site 2, 1800-4100 m) and Malari (Site 3, 3000-4000 m). At all these sites, 106 quadrate plots (10 m × 10 m) were laid randomly along the altitudinal gradient (40 plots at Lata Kharak, 40 at Malari and 46 at Bhyundar Valley).

DATA ANALYSIS

Spider samples captured in pitfall traps and using other semi-quantitative methods were used to estimate community parameters in a hierarchal fashion (plot to site to region). First, the sampling adequacy was examined from species accumulation curves. For this data were pooled across plots for each site and rarefaction (by numbers) curves were generated from 100 randomizations using Estimates 8.0 (Colwell, 2006). The nonparametric estimators Chao1 and Jacknife2 were used to estimate the species richness of a site. Chao1 gives an estimate of the absolute number of species in an assemblage based on the number of rare species (singletons) in a sample. An estimate of Chao1 is recommended to obtain the inventory completeness value, completeness being the ratio between the observed and estimated richness. Jacknife2 has been found to perform well in extrapolation of species richness, with greater precision, less bias and less dependence on sample size compared with other estimators (Palmer, 1990, 1991). So, we derived Chao 1 and Jackknife2 estimates on 100% and 50% of the sample plots and selected the best species richness estimator between the two values on the basis of the consistency of estimates across sub samples.

Second, the spider community composition was examined in the three sampling sites along the altitudinal gradient. For this non-metric multidimensional scaling (NMS) (Kruskal, 1964) in PC-ORD version 4.17 (McCune and Mefford, 1999) was used. This technique calculated the Bray-Curtis (Sørensen index) similarity matrix between sites on the basis of species assemblages. Thereafter, it generated synthetic axes, reconstructed the distance matrix and calculated the stress as the difference between the original and synthetic similarity matrices. It reiterated the process until the best possible solution was reached in terms of minimizing the stress through the minimum number of axes. Finally, scatter plots were used to inspect the distribution of sampling plots in the reduced species space (NMS axes), grouping plots into eco-climatic classes.

Third, the patterns of species diversity were examined along eco-geographical gradients (primarily altitude; secondarily pH, humidity, ground cover, *etc*). For this, the species diversity of each plot was estimated using the Shannon-Wiener index. This index is sensitive to changes in abundance of rare species in a community and is based on the number of species in a taxon and the total number of species in a sample (Magurran, 1988). Then alternative ecological hypotheses were formulated regarding species diversity patterns corresponding to the research questions. For this,the species diversity at the plots was modelled alternately with altitude (linear and quadratic functions) and sites as random or fixed (additive and interactive) effects, along with pH and humidity. Linear and linear mixed models in SPSS version 16 release 2.0 (SPSS Inc., Chicago, IL, USA) were used and candidate models compared using the Bayesian information criterion (BIC). This exercise described the most robust and parsimonious species diversity pattern in this region.

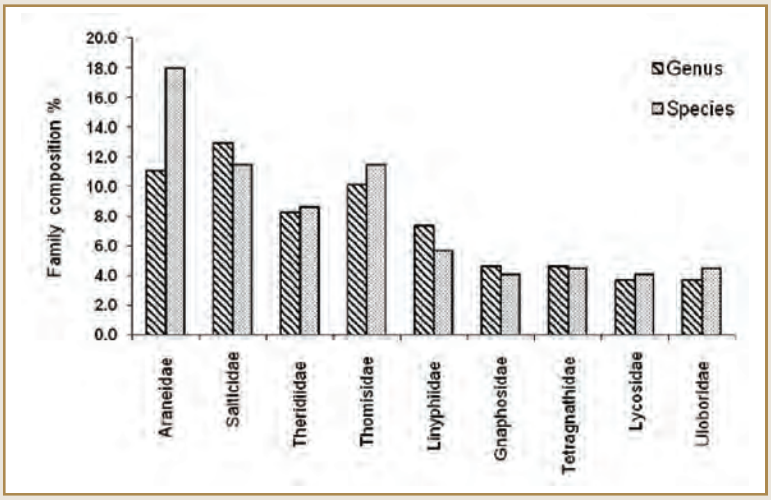
Lastly, the effect of altitudinal gradient on the species diversity across guilds was examined. For this, the species were grouped into functional groups or guilds. These guilds were grouped based on the available information on their habitat preferences and predatory methods. Thus, they were classified into three major guilds (PW, plant wanderers; GW, ground wanderers; WB, web builders). Similarly, as in the foregoing, the values of the species diversity at plots were estimated using the Shannon-Wiener index and regressed with altitude at the different sites. The altitudinal patterns of shrub and herb diversity were examined simultaneously. However, the tree diversity was not quantified as the canopy spider diversity was beyond the scope of this study.

RESULTS

SPIDER DIVERSITY AND COMPOSITION

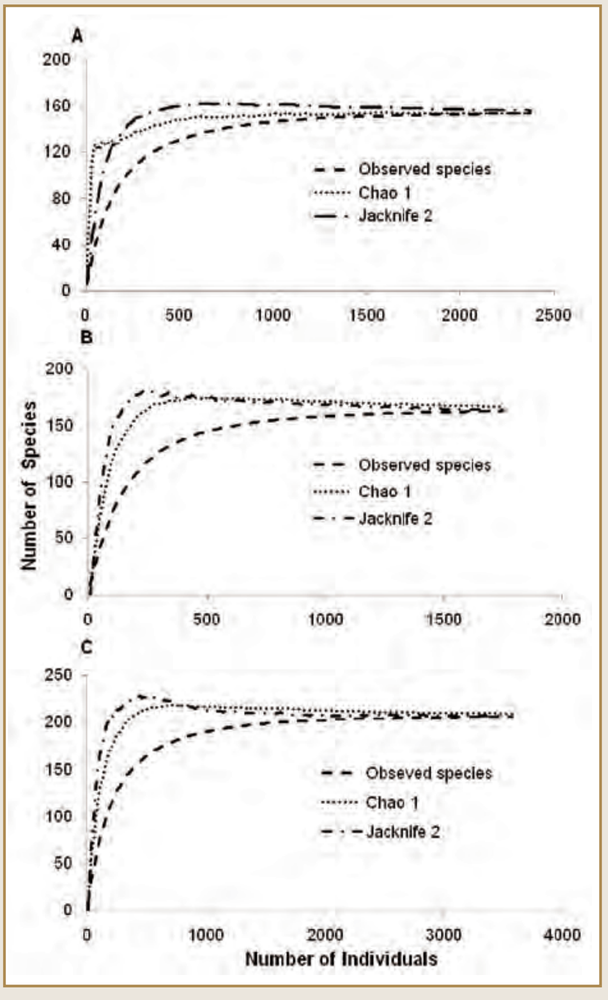
A total of 244 species belonging to 108 genera and 33 families were collected during the entire sampling period. It was observed that the family with the highest number of total species was the family Araneidae, with 18% (44 species), followed by the families Salticidae and Thomisidae, with 11.5% (28 species) each, Linyphiidae, with 7.4% (14 species), Uloboridae and Tetragnathidae, with 4.5% (11 species) each, Theridiidae, with 8.6% (21 species), and Gnaphosidae, Oxyopidae, Sparassidae and Lycosidae, 4.1% (10 species) each (Fig. 2). The species accumulation curve (pooled for each site) reached an asymptote for both the Chao1 and Jackknife2 estimators, indicating that the sampling efforts were adequate at the regional level for all the three sites and caught most of the species that occur there (Fig. 3). The total species richness estimated using the abundance-based Chao1 predicted the richness at the three sites as 153.43 ± 0.9 (Lata Kharak), 162.75 ± 1.24 (Malari) and 206.43 ± 0.9 (Bhyundar Valley). This indicated that the inventory was complete at the regional scale (91%).

Figure 2 .



The contributions of families of spiders (>4.0%) in the NDBR in terms of total number of genera and species recorded during the entire sampling period, expressed as percentages

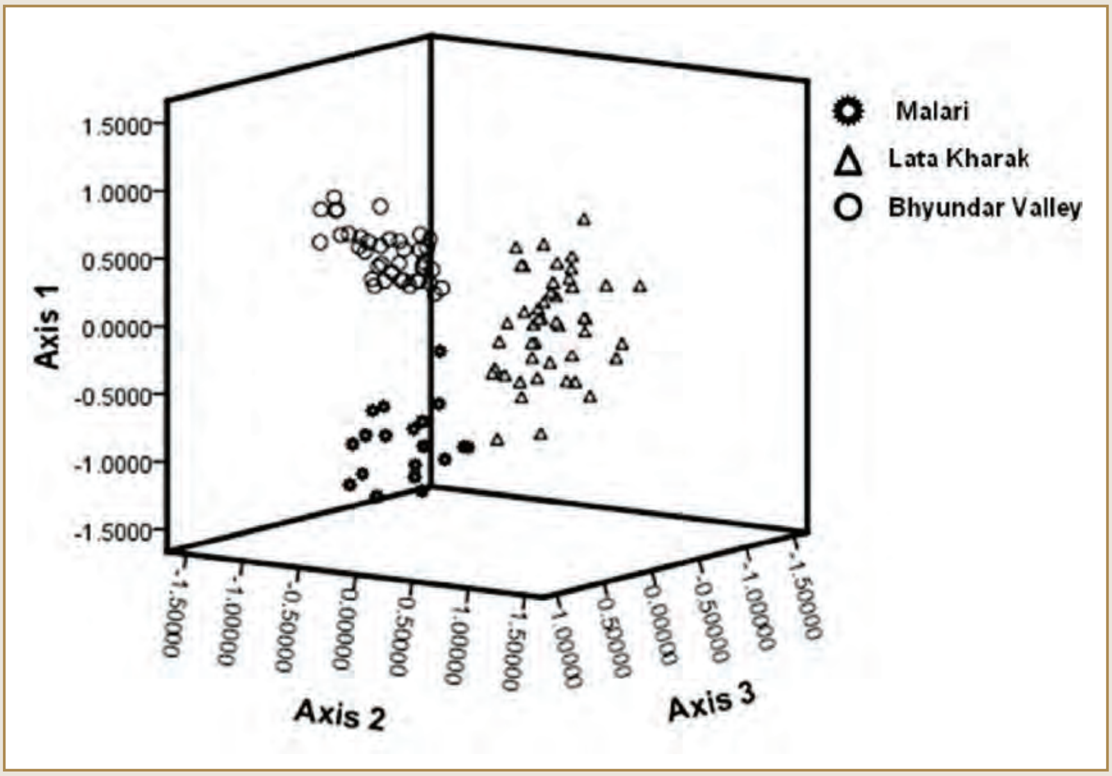
Figure 3.



Species accumulation curve and estimation curves of Chao1 and Jacknife 1 for (A) Lata Kharak, (B) Malari and (C) Bhyundar Valley (all samples pooled for each site)

COMMUNITY COMPOSITION

Figure 4.



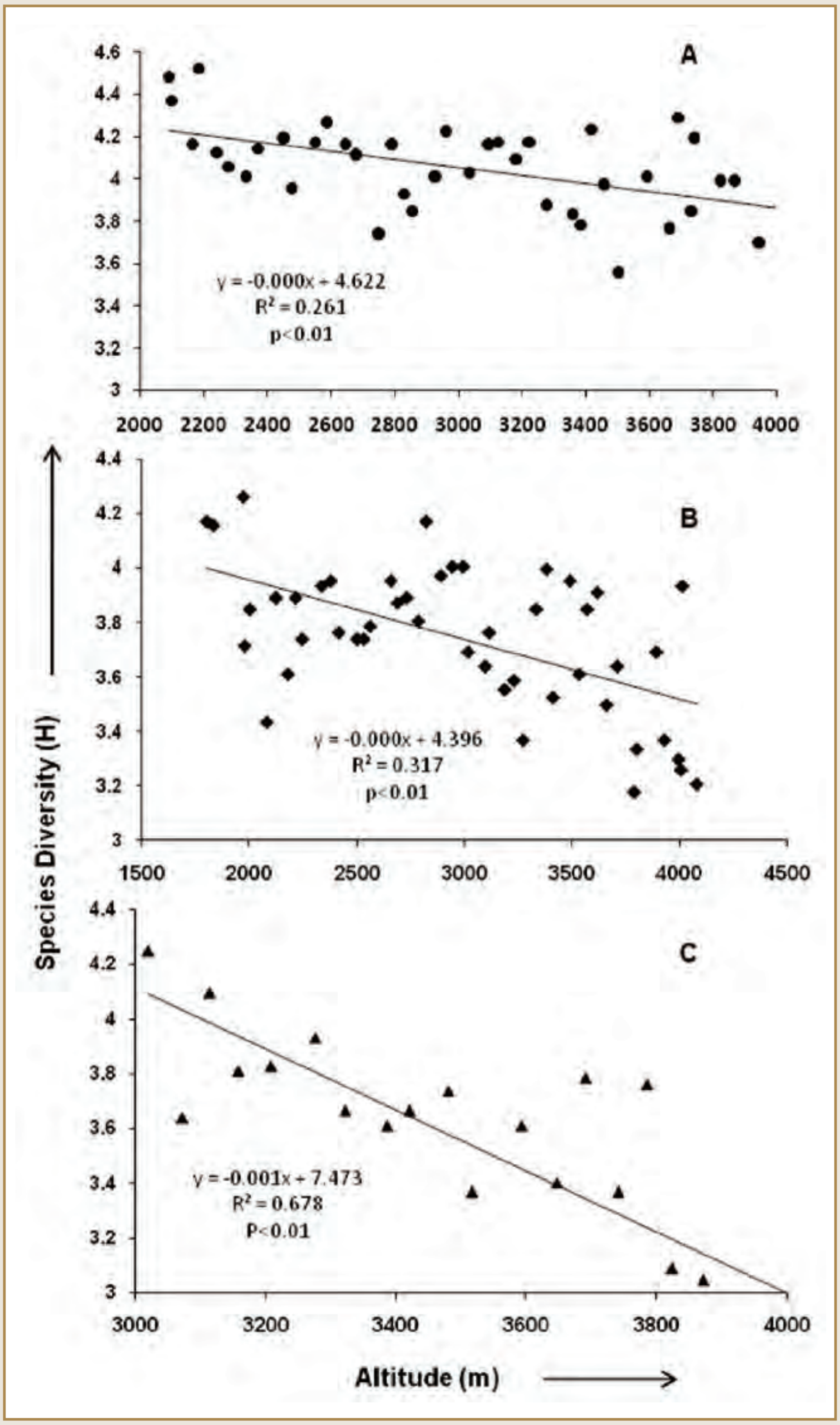
NMDS graph showing spider species composition across the three sampling sites (stress, 17.32; number of iterations, 400)

The mean altitudes of the three sampling sites, viz. Lata Kharak (2.78 ± 0.57 km), Bhyundar Valley (3.13 ± 0.62 km) and Malari (3.53 ± 0.32 km), differ significantly from each other ($F_{2, 103} = 12.78$ and $p < 0.001$; Fig. 4). The plots sampled at the three sites were plotted in a three-dimensional space from the NMS in PC-ORD. The plotting was done mainly to interpret the dissimilarities between the plots of the three sites on the basis of the spider species composition recorded from each plot. The NMS graph shows distinct clusters of the sampled plots for the three sites, which reveals that the three sites are different from each other in terms of species composition. The three sites, having different altitudinal ranges, acted as three distinct habitats with different species composition. Thus, different altitudinal ranges influence spider species composition as a whole in the NDBR landscape.

PATTERNS OF SPIDER DIVERSITY ACROSS ALTITUDINAL GRADIENT

Species diversity declined linearly across the three sampling sites (Fig. 5).

Figure 5.



Patterns of species diversity along the altitudinal gradient in the three sampling sites: (A) Lata Kharak, (B) Bhyundar Valley and (C) Malari

The Pearson's correlation matrix at the regional scale indicated that the species diversity was negatively related to altitude. However, the explanatory variables were not correlated (Table 1).

Table 1.

Pearson's correlation matrix for the habitat covariates with regional species diversity (sites combined) as the dependent variable

Variable	Diversity	Altitude (km)	Temperature (°C)	Ground cover (%)	Humidity	Litter depth (mm)	pH
Diversity	1	-0.476	-0.04	0.056	-0.113	-0.029	-0.244
Altitude (km)	-0.476*	1	-0.011	-0.171	0	0	0
Temperature (°C)	-0.04	-0.011	1	-0.193	0.033	-0.031	0.152
Ground cover (%)	0.056	-0.171	-0.193	1	-0.11	0.069	-0.014
Humidity	-0.113	0	0.033	-0.11	1	-0.223	0.074
Litter depth (mm)	-0.029	0	-0.031	0.069	-0.223	1	0.097
pH	-0.244**	0	0.152	-0.014	0.074	0.097	1

** Correlation is significant at the 0.001 level.*

*** Correlation is significant at the 0.05 level.*

Table 2.

The regional species diversity patterns could be explained most parsimoniously and robustly as an interactive effect of site and altitude (Table 2).

Model	Parameters (number)	-2 Log L	AIC	BIC	ΔBIC
D ~1	2	75.6	79.6	84.9	43.6
D ~1+alt	3	48.4	54.4	62.4	21.1
D ~1+alt+alt²	4	48.3	56.3	66.9	25.6
D ~(1/site)+alt	4	35.3	43.3	54	12.7
D ~(1/site)+alt+alt²	5	35.3	45.3	58.6	17.3
D ~1+site+alt	5	25.2	35.2	48.6	7.3
D ~1+site+alt+alt²	6	25.2	37.2	53.2	11.9
D ~1+site*alt	7	8.6	22.6	41.3	0
D ~1+site*alt²	8	5.9	21.9	43.2	1.9
D ~1+site*alt+pH	8	6.3	22.3	43.6	2.3
D ~1+site*alt+humidity	8	8.4	24.4	45.7	4.4

Comparison of alternate candidate models to describe species diversity (D) using information theoretic approach; model parameters,-2 loglikelihood value, Akaike's Information Criterion (AIC), and Bayesian Information Criterion (BIC)and ΔBIC have been reported. The best-fit model predicted the spider species diversity to be an interactive function of region and altitude.

Table 3. Parameter estimates for the best-fit model

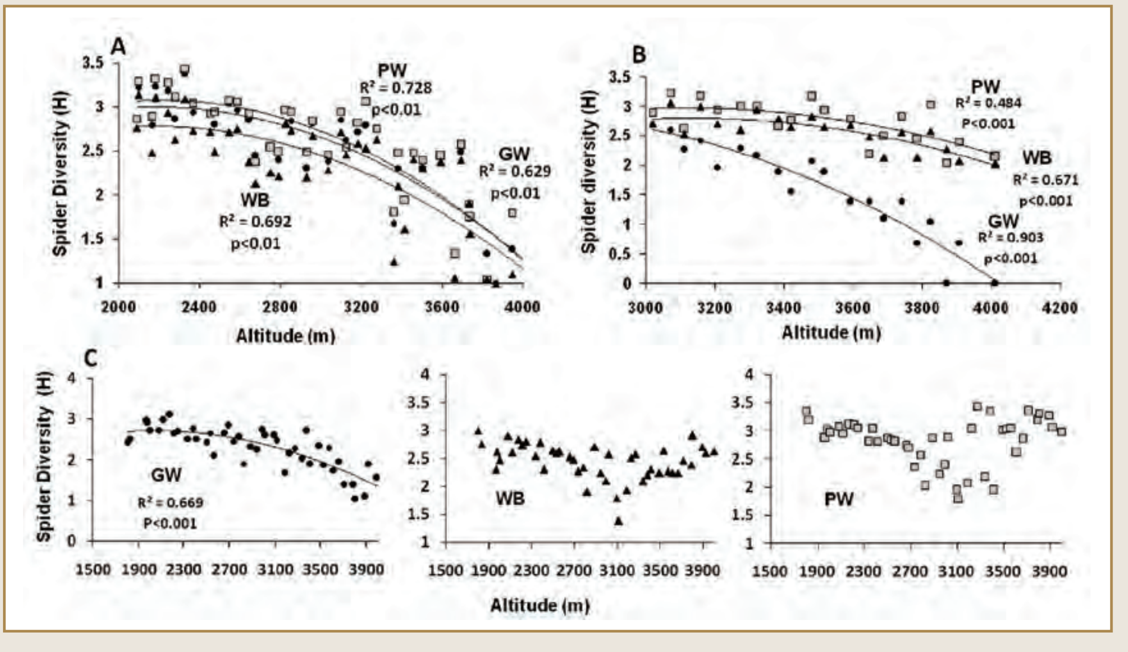
Parameter	ß	Standard error	T	Sig.
Intercept	6.70	0.63	10.60	0.01
Lata Kharak	-2.20	0.66	-3.31	0.00
Bhyundar Valley	-2.68	0.66	-4.05	0.00
Altitude_km	-0.89	0.18	-4.97	0.00
Lata Kharak * Alt(km)	0.73	0.19	3.80	0.00
Bhyundar Valley * Alt(km)	0.80	0.19	4.24	0.00

The best fit model indicated that the species diversity declined linearly, by 0.89 units with unit increase in altitude (km). Compared with Malari, the species diversity values of Lata Kharak and Bhyundar Valley were less by >2 units. However, the rate of altitudinal decrease of species diversity was less in Lata Kharak and Bhyundar Valley, compared with Malari (Table 3).

GUILD DIVERSITY PATTERN ALONG ALTITUDINAL GRADIENT

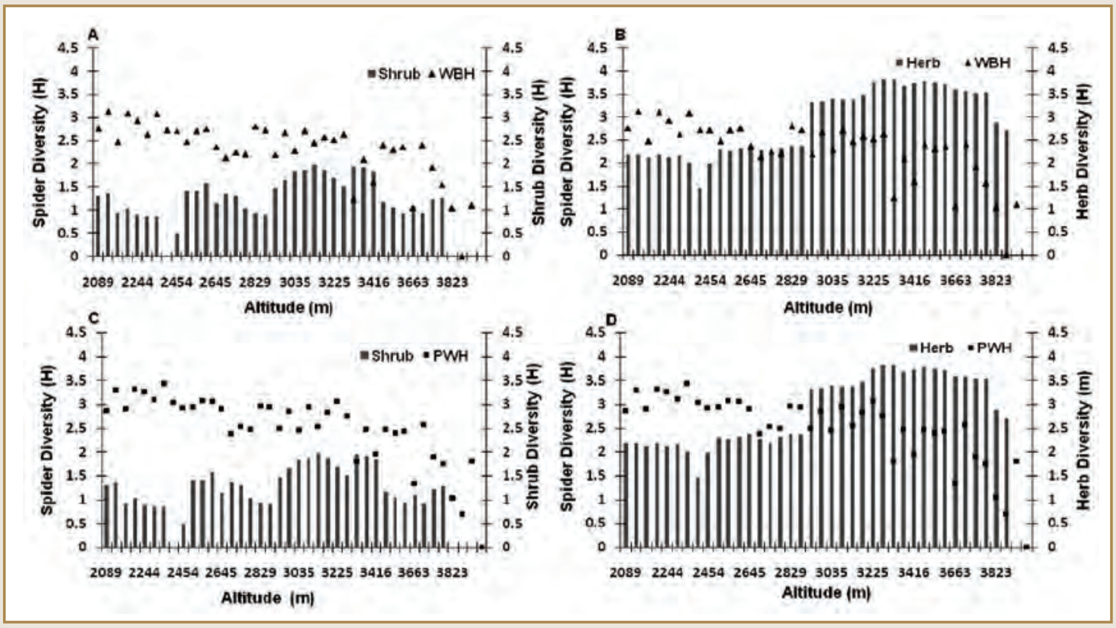
Guild-wise analysis across the elevations showed that among the three guilds (GW, PW, WB), the ground-dwelling spiders had a hump-shaped decline in all the three sampling sites. The responses of the other two guilds, PW and WB, to the altitudinal gradient differed in all the three sampling sites. In Malari and Lata Kharak, the distribution first gradually increased with altitudinal gradient and was maximum at a moderate elevation, after which it decreased gradually with a further increase in the altitude. However, in the third site (Bhyundar Valley), both the guilds did not show any distinguishable trend (Fig. 6). The patterns of herb and shrub diversity were also tested. It was observed that in Lata Kharak and Bhyundar Valley the herb diversity increased with increasing elevation, whereas the pattern of shrub diversity was not very clear (Figs. 7 & 8). In Malari both the herb diversity and shrub diversity showed a declining pattern with increasing altitude (Fig. 9).

Figure 6.



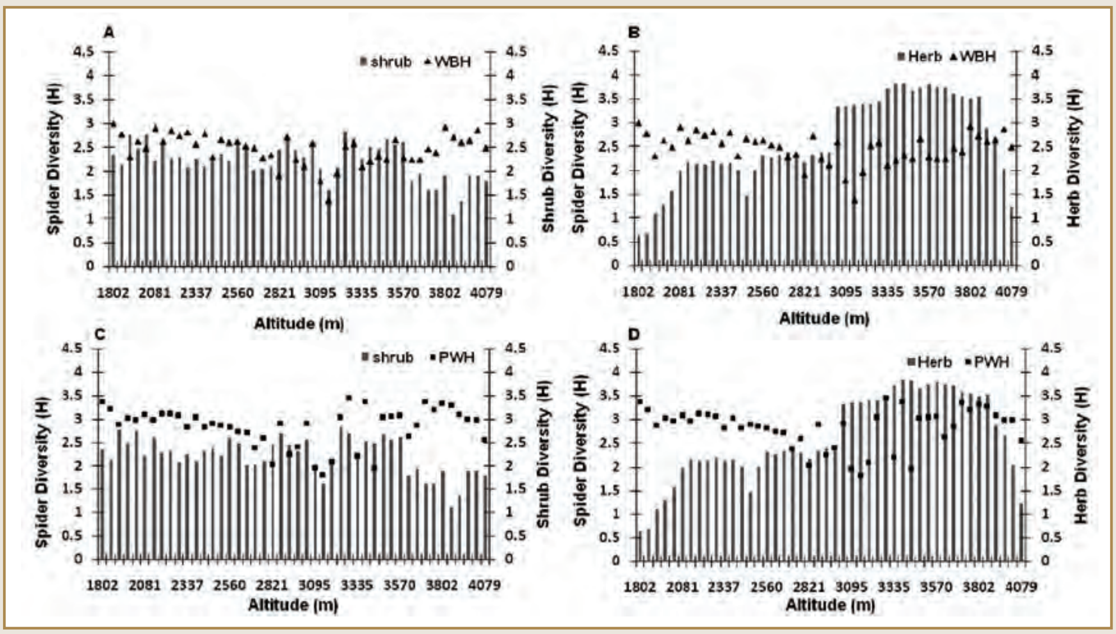
Guild diversity patterns in the three sites: (A) Lata Kharak, (B) Malari and (C) Bhyundar Valley

Figure 7.



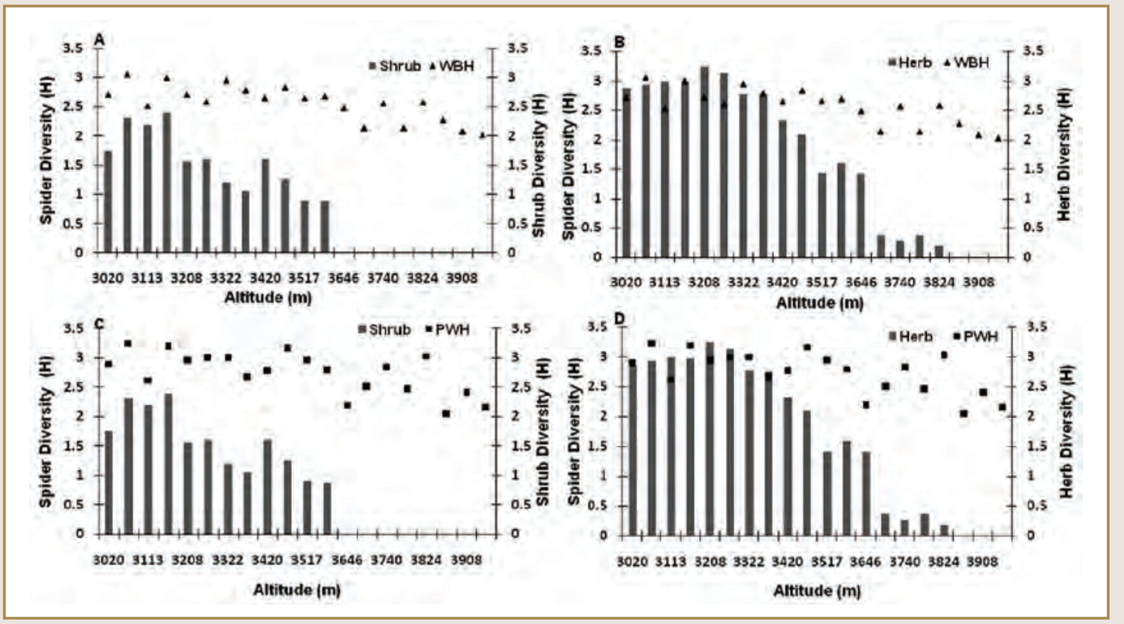
Patterns of guild diversity of spiders (A-B, WB (web-building spiders); C-D, PW (plant–wandering spiders) along with herb and shrub diversity at Site 1 (Lata Kharak)

Figure 8.



Patterns of guild diversity of spiders (A-B, WB (web-building spiders; C-D, PW (plant–wandering spiders) along with herb and shrub diversity at Site 2 (Bhyundar Valley)

Figure 9.



Patterns of guild diversity of spiders (A-B, WB (web-building spiders); C-D, PW (plant–wandering spiders) along with herb and shrub diversity at Site 3 (Malari)

DISCUSSION

It is increasingly important to understand patterns of species diversity in the high-altitude regions of the Indian Himalaya and obtain baseline data with which to compare future changes resulting from spatial shifts in climate and habitat. This study quantifies spider assemblages and shows that spiders partition space and habitat according to the niche they occupy along elevational gradients. A total of 244 species belonging to 108 genera and 34 families were documented during the entire sampling period. This represents 16.1% of the species diversity, 28.6% of the generic diversity and 56.7% of the family diversity reported from India (Sebastian and Peter, 2009). Some of these families and species were observed to have limited distributions, but this may be because they are cryptic or have patchy distributions and thus may not have been adequately sampled.

The results showed that the species diversity decreased with increasing altitude in all the three sampling sites. As spiders are sensitive to small changes in the environment, especially changes in the vegetation, topography and climate, the patterns of linear decline are probably related to the more severe climatic conditions, terrain and landscape of the NDBR, leading to species declines and absences of less tolerant species. Similar findings of spider abundance declining linearly with elevation were observed in the studies of Otto and Svensson (1982) and McCoy (1990). Along the altitudinal gradient of NDBR, two main patterns are evident: first, a steady decline in family diversity, and then, a hump-shaped decline of species. Species are gradually filtered out depending on their tolerance and appropriate habitats, and in most cases they are not replaced by others. From the guild-wise variations with elevation, it was observed that the ground-dwelling spiders showed a hump-shaped decline in all the three sampling sites. Chatzaki *et al*. (2005) also found similar results in Crete: along a broad elevational gradient, the richness of ground-dwelling spiders showed a hump-shaped response to changes in elevation. However, similar hump-shaped responses of plant wanderers and web builders were found in Lata Kharak and Malari, but there was no effect of elevation on these guilds in Bhyundar Valley. The hump shape could be the result of a greater habitat diversity and stability of environmental factors as compared with the higher-altitude zones.

For ground-dwelling spiders, the timberline does not play any major role (Chatzaki *et al.*, 2005). Because they live on the ground, the changing vegetation above the timberline does not affect them directly but only through a decline in food availability, which results from the reduction of habitat diversity and complexity. However, with other spider families that are probably dependent on the vegetation type of their habitat due to their way of life and foraging, the vegetation plays a significant role in shaping these communities. In particular, the formation of ground vegetation and the resulting microclimate are most likely to affect the diversity and distribution of ground-dwelling spider species, and this is probably a major reason for the formation of specific species assemblages in a habitat (Bultman and Uetz, 1982; Hurd and Fagan, 1992; Gibson *et al.*, 1992). The patterns of species diversity and species composition are probably related to harsh climatic conditions (such as extremes of temperature, humidity, precipitation, wind intensity) and to the landscape, leading to a species decline and an absence of less tolerant species. Species richness is supposed to peak at mid elevations via primary productivity, which is considered to peak at mid elevations. However, Jiménez-Valverde and Lobo (2007) found that spider richness was more strongly correlated with habitat complexity and maximum temperature than with elevation at a regional scale of investigation. Earlier works suggest that species diversity is correlated with the structural complexity of a habitat (Uetz, 1979; MacArthur, 1964; Pickett *et al*., 1991; Androw, 1991; Hawksworth and Kali-Aroyo, 1995; Rosenzweig, 1995). As the habitat structure and complexity change with increasing altitude, shifts in the composition of potential prey species are also expected to occur; supporting a dual process that is probably determining spider assemblages in the area. However, some families, such as the Lycosidae, which are more tolerant and overcome harsh conditions, were also collected from higher elevations.

Changes along spatial gradients associated with changes in habitat can have significant effects on the structures of spider assemblages, but responses vary among sites at different altitudes. Studies conducted by Samu *et al*. (1999) in agricultural ecosystems found that spider abundance/diversity and environmental (including microclimate, habitat and disturbance) diversity were, in general, positively and variably correlated at different scales. Hore and Uniyal (2010) found that habitat heterogeneity in the Terai Conservation Area is mediated largely by the structural diversity of the vegetation rather than microclimatic variations. Structural changes in the vegetation tend to override imminence much before any microclimatic change takes effect in space. Studies have confirmed that residence time is related to disturbance or web destruction (Enders, 1974; Hodge, 1987), microhabitat features such as temperature and humidity (Biere and Uetz, 1981), growth of the spider and an appropriate change in the structural requirements of web construction (Lubin *et al.*, 1993) and prey capture success (Bradley, 1993; McNett and Ryptra, 1997).

From the ordination analysis performed using NMS, it was found that the species composition differed in different mountain systems. It is possible that with increasing altitude, resources get limited and only the tolerant species are able to cope. NMS has been used as a tool for descriptive multivariate data analysis, and the principles and mechanics have been documented well (McCune and Grace, 2002). NMS is well suited to community data, particularly when the ***β*** diversity is high (i.e., the data matrix contains many zeroes) (Faith *et al.*, 1987), and permits robust analysis of many data types. In analyses of simulated data with known gradients, NMS has shown a superior ability to recover the underlying data structure compared wtih principal components analysis, principal co-ordinates analysis and reciprocal averaging (Fasham, 1977; Minchin, 1987).

There are several other environmental factors that may also affect the spider species diversity apart from altitude and seasonality, *viz.,* spatial heterogeneity, competition, predation, habitat type, environmental stability and productivity (Rosenzweig, 1995). Other factors are important in influencing spider diversity and species richness in the Himalayan ecosystem, *viz.*, intra- and inter-specific competition, surrounding habitats and climatic factors. However, the role of biotic factors cannot be ruled out as the availability of food and processes such as dispersal may also significantly influence the dynamics and structuring of spider assemblages. Shifts in vegetation structure are also expected to assist changes in diversity, and as the abundance of arthropods such as spiders depends heavily on arthropod prey, dynamic shifts in the prey base are likely to limit the spider assemblage.

The NDBR has an interestingly diverse spider fauna. Similar research in other parts of the biosphere reserve will surely supplement the available information. It is also important to note that the spider fauna is ubiquitous in nature and that its diversity cannot be explained by quantifying any one aspect of the environment. It does depend on many other factors or a combination of factors, apart from altitudinal variations and habitat structure. Looking into these factors will surely bring in more interesting results of relevance to the maintenance and management of this diversity.

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WILDLIFE INSTITUTE OF INDIA
Chandrabani, Dehradun-248001
t.: +91-135-2640111-115, 2640304
f.: +91-135-2640117
e.: envis@wii.gov.in; wii@envis.nic.in
www.wiienvis.nic.in

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