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

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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.

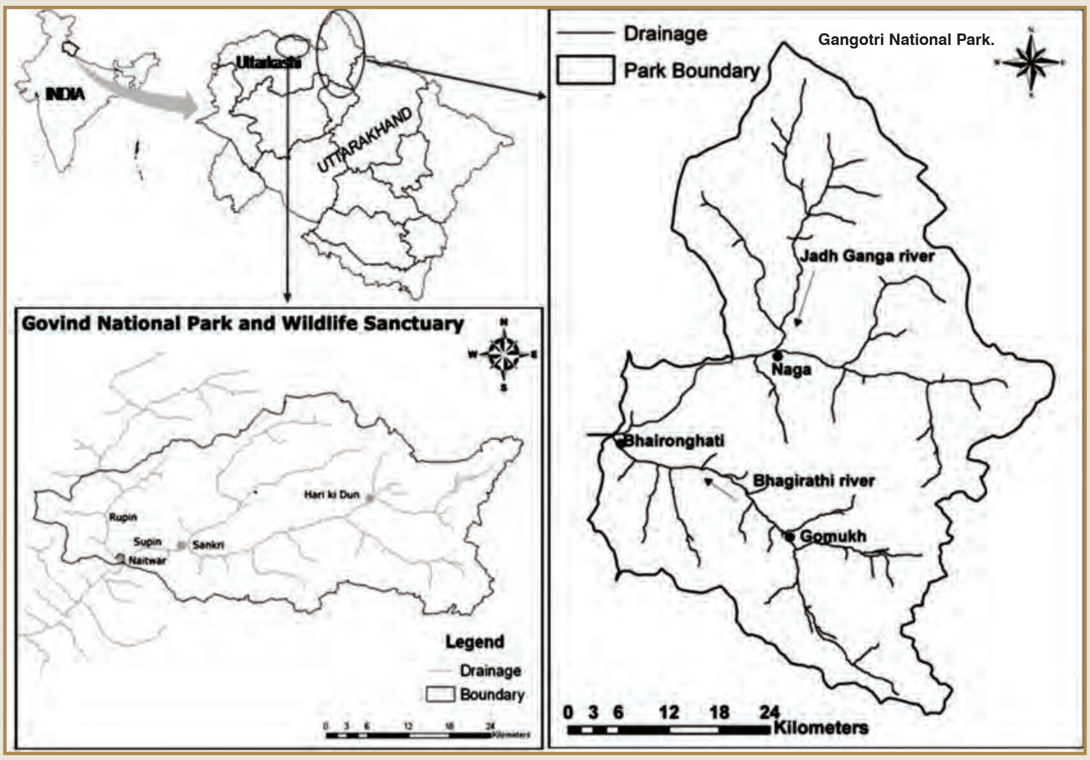
The objectives of the study were to investigate the moth species composition in different vegetation zones within the Gangotri Landscape Area and to compare sites in terms of their family and species compositions. In addition, a preliminary attempt was made to identify different indicator species of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

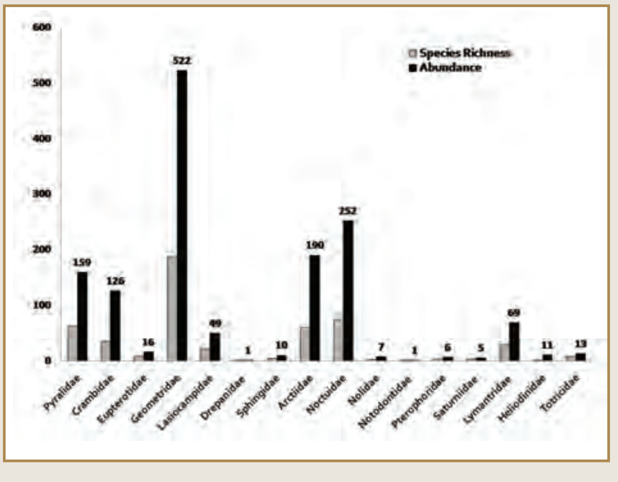
Sampling Site	Location	Protected Area	Altitude (m)	GPS Co-ordinates	Major Vegetation Zones
Chir Pine Forest	Naitwar	GWS	1450	31°04'07.5" N 78°06'21.4" E	Chir Pine
Riverine Mix Forest 1	Bhatwari	GNP	1530	31°04'07.5" N 78°06'21.6" E	Mixed Riverine
Riverine Mix Forest 2	Dhaula	GWS	1580	31°07'40.7" N 78°02'41.0" 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.

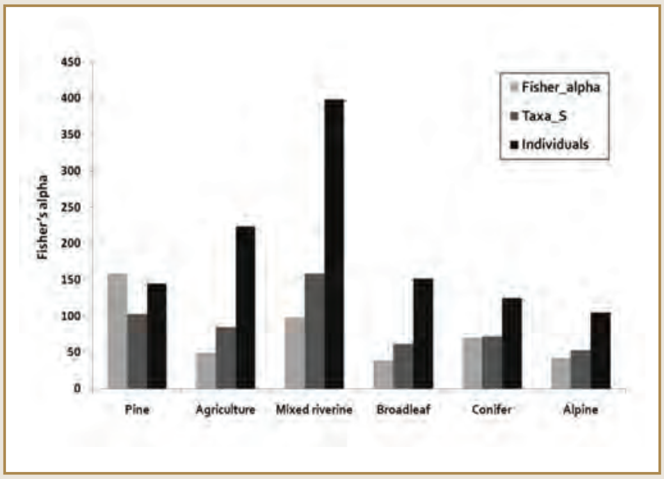


Species richness and abundance of 16 families recorded altogether in the study area. The family Geometridae was the most dominant family, followed by the families Noctuidae, Arctiidae and Pyralidae.

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).

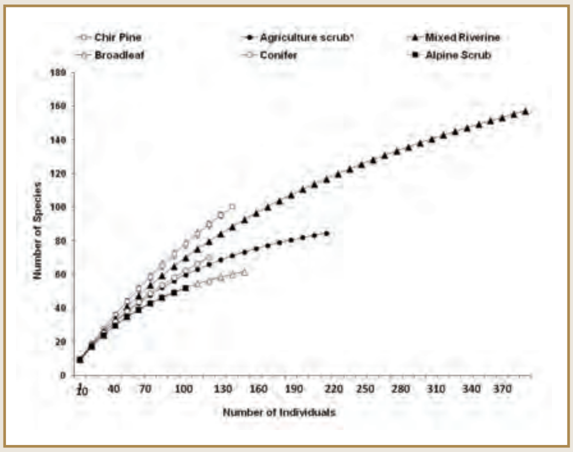
Figure 3.



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.

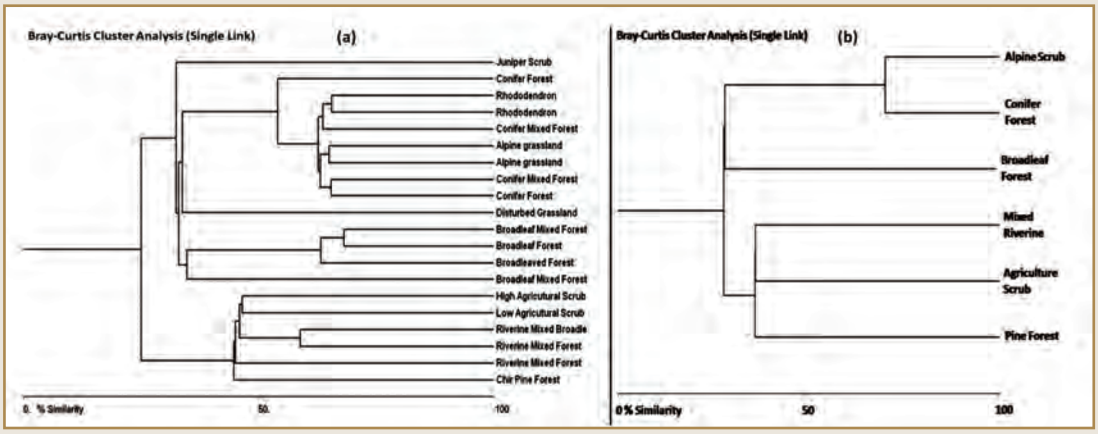
Measures of species richness estimates and inventory completeness for each vegetation zone and for the regional data set. Richness estimator values (Chao 1 and Jackknife2) represent the mean of 100 randomizations of sample order. The ratio of estimated and observed richness based on Chao 1 represents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

ACKNOWLEDGEMENTS

The authors are grateful to the Director and Dean, Wildlife Institute of India, for the funding necessary for this study and to the Director, Zoological Survey of India, for guidance and support. Thanks to the Uttarakhand Forest Department and the field staff of Gangotri and Govind National Park for providing the necessary permission and logistics for conducting the study. The staffs of the Central Zone Regional Centre, Jabalpur, and Headquarters, Kolkata, Zoological Survey of India, are acknowledged for assisting during specimen identification and literature consultation. The work would have been literally impossible without the help of three field assistants, Jaigeer Lal Bharti, Deep Singh Chauhan and Mathabar Singh Rawat.

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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

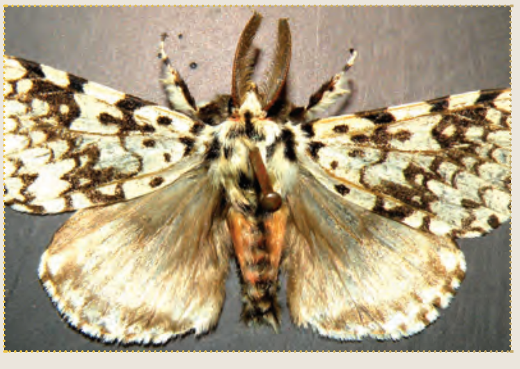
Aletia medialis Smith 1894

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