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Impact of mining activity on butterfly diversity and community composition

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Abstract
The distribution and composition of butterfly assemblages was studied along a disturbance gradient caused by mining activity, in Singrauli, Madhya Pradesh, in India. Mining activity was found to have a negative impact but revegetation had a strong positive impact on butterfly community richness. The overall abundance, diversity and richness of the butterfly assemblages, therefore, increased with increase in mine site restoration. Correspondence analysis reveals that most species belonging to family Nymphalidae demonstrate a strong positive association with the highly disturbed sites and are thus disturbance tolerant. This may be because Nymphalidae such as *Danaus genutia* and *Danaus chrysippus* feed on the nectar of a wide variety of weeds such as *Euphorbia hirta*, *Calotropis gigantea* and the invasive species, *Lantana camara,* found in disturbed mine sites. In contrast, some butterfly species such as *Ixias pyrene, Eurema hecabe,* and *Papilio polytes* were found to be sensitive to disturbance regimes. The absence the latter species from moderately and highly disturbed sites may be due to the larval host plant preferences since the least disturbed and reference sites were characterized by higher diversity and more mature plants. Thus, butterfly assemblage composition appears to be a good predictor of mine site restoration success.

Keywords: Coal mine spoils, Environmental degradation, Insect diversity, Revegetation

1. Introduction

Anthropogenically caused environmental degradation and the consequent adverse impact on biodiversity are of worldwide concern. The restoration of degraded lands such as mine sites is a priority area in the area of conservation biology [1, 2]. The field of restoration ecology is concerned with the return of the degraded land to its natural state, recreating the entirety of an ecosystem including the flora and fauna [3]. The influence of environmental disturbances in shaping biodiversity is now widely recognized [4]. The success of ecological restoration depends not only on creation of vegetation cover, but also on the recolonization of the restored sites by a characteristic assemblage of fauna that is comparable with that occurring at the undisturbed reference sites [5].

Coal mine spoils are the piles of accumulated over-burden excavated during the mining process, which cause ecosystem degradation by destruction of the natural ecosystem [6]. Mining activity causes massive destruction of the flora and fauna by large-scale alteration of the topography and modification of the physico-chemical properties of the soil. Disturbances in terrestrial ecosystems can affect both vertebrate [7, 8] and invertebrate community [3] structure and functioning. However invertebrate biodiversity reportedly reflects trends in species richness and community composition more accurately than vertebrates, due to their higher diversity, abundance, small size, short generation times and sensitivity to local microclimatic conditions [9]. Moreover, many species of insects are not only highly mobile but also exhibit rapid responses to environmental changes. This makes them more effective indicators of environmental degradation [10].

Order Lepidoptera is the second largest order in the class Insecta and constitutes an important component of terrestrial biodiversity [11]. The extent of species diversity in an ecosystem depends upon their adaptability to particular micro-habitats present in that area [12] Butterflies constitute sensitive biota since they are severely affected by the environmental variations and changes in the plant community structure due to their close dependence on plants [13]. Apart from being highly sensitive to any environmental change, they are also easy to observe and taxonomically easy to identify [14, 13]. This makes the study of the response of butterfly communities to disturbance relatively easier. Butterfly assemblages are found to have utility in the evaluation of the direct and indirect effects of environmental change [14], including changes in climate [15]. Further, butterflies have been considered as a representative of other insect groups such as ants, beetles, spiders and crustaceans [16-19].

The Indian sub - continent has about 1439 species of butterflies, out of which 100 species are endemic to it and at least 26 taxa are today globally threatened as per the Red List of threatened animals and insects [20]. Moreover, butterflies have potential as bioindicators [21]. Inspite of the extensive literature available on the impact of disturbance regimes on insects only limited information is available on the impact of environmental degradation on butterfly communities [22].

Environmental heterogeneity reportedly results in increased butterfly diversity and richness in the xeric areas [23]. Higher number of species was recorded in the meadows and lower at reclaimed dump sites [24]. Urbanization has been associated with an overall decrease in butterfly richness and adversely impacts on rare species [22]. The body size of the butterflies and their distribution also demonstrate changes along latitudinal gradients [25, 26]. The relationship between butterfly community composition and various types of disturbances in tropical and Savannah forests reveals increase in diversity and abundance of generalist species and decline in the number of specialist species [27]. Environmental degradation due to anthropogenic activities including logging [28] urbanization, [22] agricultural practices, [29] grazing of livestock, [30] greatly affect both butterfly diversity and abundance. However, scanty information is available on the impact of mining activities on butterfly community structure [31, 32]. In the present study, an attempt has been made to investigate the changes in the distribution and composition of butterfly assemblages in mine sites of different ages, showing different levels of disturbance.

2. Materials and Methods

2.1 Study Site

Field work was conducted in 3 categories of coal mine spoils: highly disturbed; HD (0 and 2 year old), moderately disturbed; MD (4 and 6 year old) and least disturbed; LD (8 and 10 year old). The reference site (nearest relatively undisturbed area) was situated at about 9km distance from the Northern Coal Field Limited (NCL), Singrauli (latitudes 23° 47' to 24° 12´ N and longitudes 81° 48´ to 82° 52´ E), in Madhya Pradesh, India. About 46 plant species have been planted by the mining company after approximately 1.5 years of dumping the mined waste, at each site. The commonly occurring grasses are *Imperata cylindrica, Saccharum* sp., *Cynodon dactylon*, *Bambusa bambos, Dendrocalamus strictus, Eleusine indica, Oplismenus burmannii* and *Pennisetum pedicellatum*. Herbs include weeds such as *Parthenium hysterophorus*, *Lantana camara*, along with *Hyptis suaveolens, Datura* sp., *Eragrostis tenella, Cassia tora, Eragrostis unioloides* and *Euphorbia hirta*; shrubs comprise *Calotropis gigantea, Ziziphus nummularia, Ziziphus xylopyrus, Bougainvillea* sp. and *Asparagus racemosus.* Trees include *Cassia fistula, Cassia siamea, Acacia catechu*, *Acacia nilotica, Leucaena leucocephala, Acacia mangium, Dalbergia sissoo, Pithecellobium dulce* and *Prosopis juliflora* [33- 35]. The level of disturbance at each site has been assessed in terms of the vegetational cover.

2.2 Sampling Method

2.3 Butterfly diversity

Butterflies were sampled from March to October, 2013, by the visual scanning method. In this method a metal quadrat frame was used and the abundance and diversity of butterflies was recorded in each quadrat (area = 1 m^2) randomly placed on the ground surface. Observations were recorded in 250 quadrats per site (n = 50 per day per site, 5 days per site). The butterflies were captured by using insect net for the identification in the laboratory [36].

2.4 Vegetational cover

Vegetational cover at the mine sites was also determined by the quadrat method. A 1 m^2 iron frame (consisting of 16 small squares, each 625 cm^2 in area) was placed at each of the 50 randomly selected areas, in each study site. The types of vegetation were identified at each site by experts of the forest department associated with NCL Singrauli (Table 1)

2.5 Statistical Analysis

Butterflies species diversity and richness at each mine site was calculated according to the Shannon–Weiner (for alpha diversity); Whittaker index (for beta diversity) and Margalef index (for richness) methods.

Changes in the butterfly diversity and abundance with mine site rehabilitation was analysed by carrying out one-way analysis of variance (ANOVA) followed by Dunnett's (in case of analysis of abundance and alpha diversity) and Duncan's Multiple Range *post hoc* tests (DMRT) ($p < 0.05$), for the analysis of species richness.

Butterfly diversity at the various sites was compared using the rank abundance plot in which percentage cumulative abundance (log) was plotted against species rank. Butterfly species restricted to only 1-2 mine sites were classified as habitat specialists. Those which were consistently recorded in the reference as well as the highly disturbed sites were termed as habitat generalists. Correspondence analysis (CA) was used to study the association of butterfly species and their families to different levels of disturbances. CA is a categorization method used to separate the data in classes or clusters. Its main aim is to create a set of clusters such that objects in the same cluster are similar to each other and different from objects located in further clusters [37].

All statistical analyses were done by using SPSS (16.0) statistical package (SPSS Inc, Chicago, USA; 1997), Sigma Plot 11.0, MS Excel 2007 and Past 3.0 for CA.

3. Results

3.1 Species diversity and abundance

A total of 14 butterfly species belonging to 10 genera and 04 families: Pieridae, Nymphalidae, Papilionidae and Lycaenidae, were recorded, at the mine sites. Of these, one species each of Nymphalidae and Papilionidae were recorded only at the reference site. Three species belonging to family Pieridae and one Lycaenid species were recorded from LD and reference sites only. A total number of 09 habitat specialists and 05 habitat generalist butterfly species were recorded from the dump sites (Table 2).

3.2 Vegetational cover

Percentage of Vegetational cover increased with the age of coal mine spoils. Thus the green cover at the reference site was high (80.5%) followed by that at the LD (60.5%) and MD (45.75%) sites and was very low (12%) at the HD site (Fig.1).

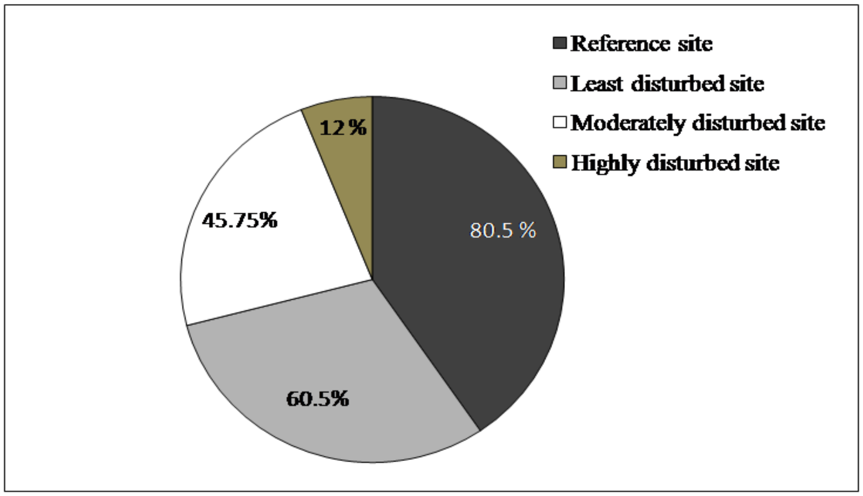

Fig 1: Green vegetational cover along a disturbance gradient (caused by mining activity) at Singrauli, Madhya Pradesh, India.

Table-1 Commonly occurring plant species in the 3 categories of mine sites at NCL Singrauli, Madhya Pradesh, India.
+ = present and - = absent; HD - Highly disturbed, MD - Moderately disturbed, LD - Least disturbed and Ref. - Reference sites.

Plant type	Sampling sites			
Grasses	**HD**	**MD**	**LD**	**Ref.**
Imperata cylindrica	+	+	+	+
Saccharum sp.	-	+	+	+
Bambusa bambos	+	+	+	-
Cynodon dactylon	-	+	+	+
Dendrocalamus strictus	+	+	+	-
Eleusine indica	-	-	+	+
Oplismenus burmannii	-	-	+	+
Pennisetum pedicellatum	+	+	+	-
Herbs				
Cassia tora	-	+	+	+
Datura sp.	-	-	-	+
Eragrostis tenella	+	+	+	+
Eragrostis unioloides	+	+	+	+
Euphorbia hirta	-	-	+	+
Hyptis suaveolens	-	+	+	-
Lantana sp.	-	+	+	+
Parthenium hysterophorus	+	+	+	+
Shrubs				
Bougainvillea sp.	-	+	-	+
Calotropis gigantea	+	+	+	+
Ziziphus xylopyrus	-	+	+	-
Ziziphus nummularia	-	+	+	-
Asparagus racemosus	-	+	+	+
Trees				
Acacia catechu	+	+	+	+
Acacia nilotica	+	+	+	-
Acacia mangium	+	+	+	+
Cassia fistula	+	+	+	+
Cassia siamea	+	+	+	+
Dalbergia sissoo	+	+	+	+
Leucaena leucocephala	+	+	+	+
Pithecellobium dulce	-	+	+	-
Prosopis juliflora	+	+	+	+

Table 2: Butterfly diversity, habitat specificity and occurrence in the 3 categories of mine sites and the reference area (ref.). + = present and - = absent; HD - Highly disturbed, MD – Moderately disturbed, LD - Least disturbed and Reference sites.

Family	Species	Habitat specificity	Sampling sites			
			HD	MD	LD	Ref.
Pieridae	*Ixias pyrene*	Specialist	-	-	+	+
Pieridae	*Eurema hecabe*	Specialist	-	-	+	+
Pieridae	*Catopsilia crocale*	Specialist	-	-	+	+
Pieridae	*Catopsilia pyranthe*	Generalist	+	+	+	+
Pieridae	*Pieris brassicae*	Generalist	+	+	+	+
Nymphalidae	*Danaus genutia*	Generalist	+	+	+	+
Nymphalidae	*Danaus chrysippus*	Generalist	+	+	+	+
Nymphalidae	*Precis almana*	Specialist	-	-	-	+
Nymphalidae	*Precis orithya*	Generalist	+	+	+	+
Nymphalidae	*Neptis hylas*	Specialist	-	-	+	+
Nymphalidae	*Euploea core*	Specialist	-	+	+	+
Papilionidae	*Papilio demoleus*	Specialist	-	+	+	+
Papilionidae	*Papilio polytes*	Specialist	-	-	-	+
Lycaenidae	*Freyeria trochylus*	Specialist	-	-	+	+

Abundance of each of the 10 butterfly species (*Ixias pyrene*, *Eurema hecabe*, *Catopsilia crocale*, *Catopsilia pyranthe*, *Pieris brassicae*, *Danaus genutia*, *Precis almana*, *Papilio demoleus*, *Papilio polytes*, *Euploea core*) at the 3 categories of mine sites showed significant variations relative to the reference site (one-way ANOVA: F= 53.792; 27.549; 23.454; 11.835; 30.031; 26.248; 12.226; 27.2; 22.857; 24.733, respectively, df =3, 16; $p < 0.001$ in each case). However, the abundance of 04 species including *Freyeria trochylus*, F = 4.528, $p < 0.05$, while in case of *Danaus chrysippus*, F = 6.501, $p < 0.01$, for *Precis orithya*, F= 6.570, $p < 0.01$ and for *Neptis hylas*, F = 5.500, $p < 0.01$ (df =3, 16 in each case) in the mined sites showed a significant variations with respect to the reference site.

Dunnett's *post hoc* test revealed significantly lower abundance of *Ixias pyrene*, *C. crocale, P. almana, P. demoleus, P. polytes* and *E. core,* at all the three mine sites ($p < 0.001$ in each case) relative to the reference site. The abundance of *E. hecabe, P. brassicae* and *D. genutia,* was significantly lower ($p < 0.001$) at the MD and HD sites. While *C. pyranthe* exhibited lower ($p < 0.001$) abundance only at the HD site (Fig. 1a-b). The abundance of all the butterfly species was found to be decrease with increase in the level of disturbance (Fig. 2a-b).

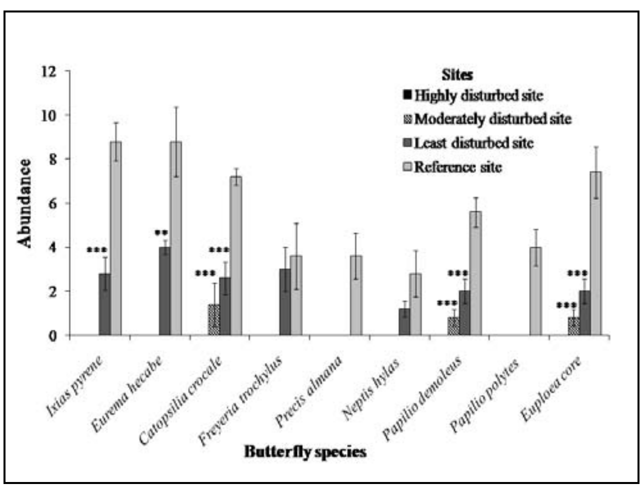

Fig 2(a): Abundance of habitat specialist butterfly species along a disturbance gradient (caused by mining activity) at Singrauli, Madhya Pradesh, India. One-way ANOVA followed by Dunnett's *post hoc* test: * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$.

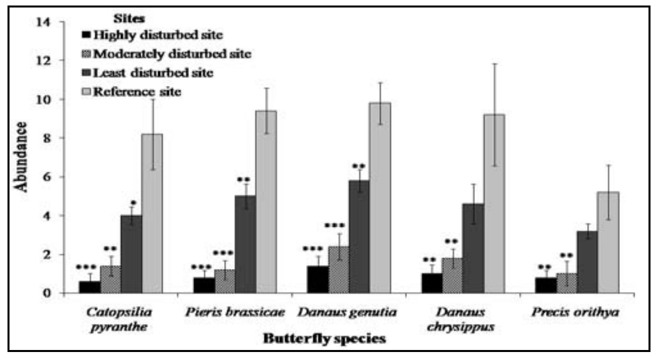

Fig 2(b): Abundance of habitat generalist butterfly species along a disturbance gradient (caused by coal mining activity) at Singrauli, Madhya Pradesh, India. One-way ANOVA followed by Dunnett's *post hoc* test: * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$.

3.3 Alpha and beta diversity

Highest alpha diversity was found at the LD site and minimum was found at the HD site. One-way ANOVA revealed significant variation ($F_{3, 16} = 570$, $p < 0.001$) in the alpha diversity. However, the *post hoc* test revealed significant lower ($p < 0.001$) diversity at the MD and HD sites, in comparison to the reference site (Fig. 3).

Beta diversity of butterflies was highest at the HD site and lowest at the LD site (Fig. 4). The k-dominance of species rank plot reveals that the maximum diversity is represented by the lower most curve i:e for the LD and reference sites while the lowest diversity is represented by the uppermost curve (for the HD site) (Fig. 5).

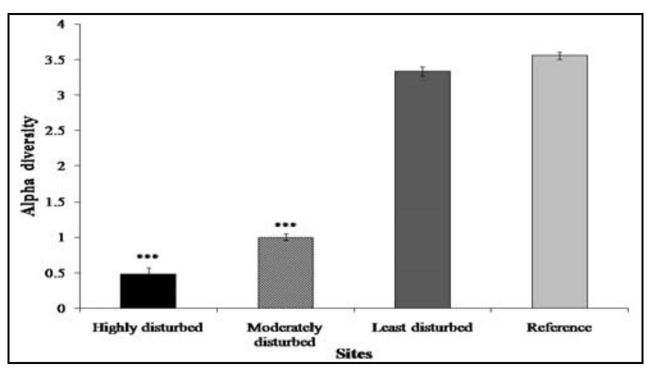

Fig 3: Alpha diversity of butterflies along a disturbance gradient (caused by coal mining activity) at Singrauli, Madhya Pradesh, India. One-way ANOVA followed by Dunnett's *post hoc* test: * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$.

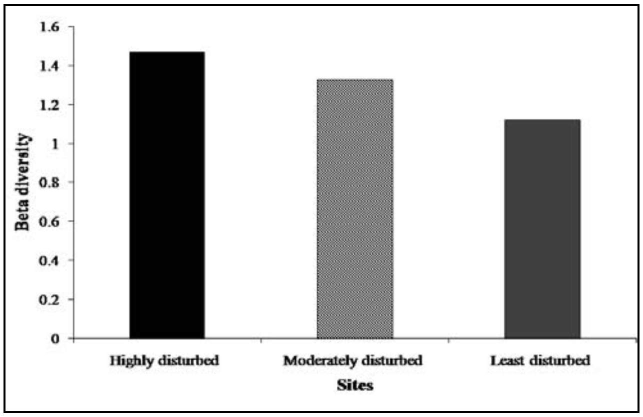

Fig 4: Beta diversity of butterfly species along a disturbance gradient (caused by mining activity) at Singrauli, Madhya Pradesh, India.

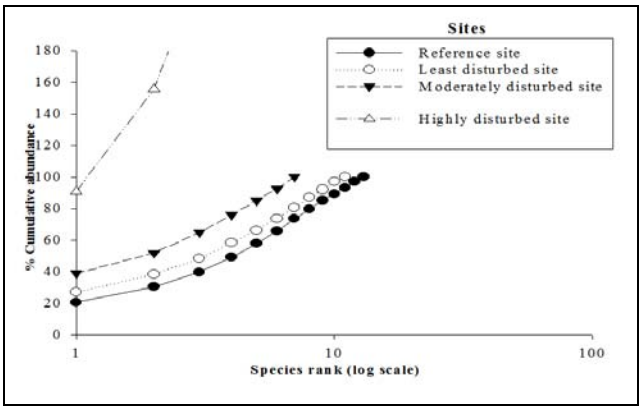

Fig 5: Species rank abundance plot of butterfly communities at different coal mine and reference sites.

3.4 Species richness

Butterfly richness was least at the HD site and highest at the LD and the reference sites. One-way ANOVA showed significant variation ($F_{3,16} = 33.004$, $p < 0.001$) in the butterfly richness across the coal mine sites. Significantly lower richness was recorded for the HD and MD sites with respect to the LD and reference sites. DMRT *post hoc* test revealed significant differences between the butterfly richness at HD and MD sites with respect to the reference site, while no significant difference was found between the LD and reference sites (Fig. 6)

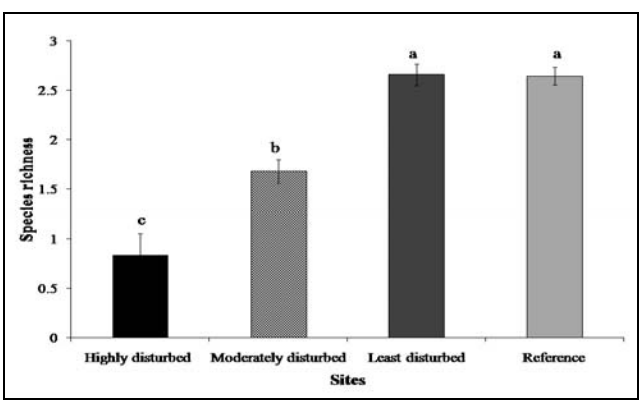

Fig 6: Butterfly species richness species along a disturbance gradient (caused by mining activity) at Singrauli, Madhya Pradesh, India. One way ANOVA followed by Duncan's Multiple Range Test (DMRT) ($p < 0.05$) were used to compare the calculated butterfly species richness different gradient of disturbed site of coal mine. Different letters denote significant differences ($p < 0.05$).

3.5 Multivariate analysis

Correspondence analysis (CA) was used to determine whether patterns in butterfly distribution could reflect the disturbance levels of different mine sites. Family-wise distribution revealed a significant impact of disturbance on butterfly families for the axis-1 and 2 which explain 85.04% and 14.49 % of the respective variations. 2D CA ordination clearly distinguishes between the various sites. CA analysis reveals that 02 butterfly families, namely Pieridae and Papilionidae prefer the least disturbed and reference sites, while HD and MD sites are preferred by members of the Nymphalidae family (Fig.7).

Correspondence analysis of butterfly species distribution with respect to the mine sites characterised by the different levels of disturbance reveales significant site preferences, explained by 90.37% and 7.12 % variation for the axis 1 and 2 respectively (Fig.8). Butterfly species, *C. pyranthe* and *P. brassicae* prefer the LD site. However, *P. almana, P. demoleus, P. polytes, E. core, C. crocale, E. hecabe, N. hylas* and *I. pyrene* prefer the reference site. *Danaus genutia, P. orithya* and *D. chrysippus* mainly prefer the HD and MD sites

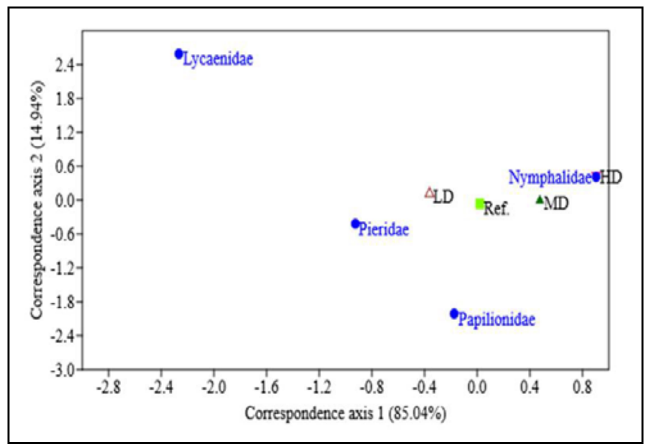

Fig 7: Correspondence analysis of habitat related distribution of butterfly families in coal mine sites with different levels of disturbances and reference site at Singrauli, Madhya Pradesh, India. Ref. - reference; LD- least disturbed; MD- moderately disturbed and HD- highly disturbed sites.

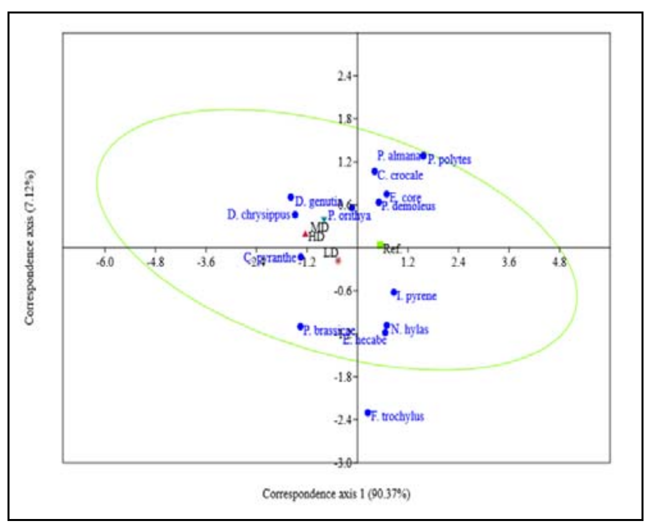

Fig 8: Correspondence analysis of habitat preferences of butterfly species (in coal mine sites with different levels of disturbances) and the reference site at Singrauli, Madhya Pradesh, India. Ref. - reference; LD- least disturbed; MD- moderately disturbed and HD- highly disturbed sites.

4. Discussion

The results of the present study reveal the impact of mine site related disturbances on the abundance and composition of butterfly assemblages. The results reveal an increase in abundance, diversity and richness with increase in vegetational cover, during the process of mine site restoration (Fig. 1, 2 a-c; 3, 4 and 5). Alpha diversity of butterflies increased with restoration of the mine sites (Fig. 3). Beta diversity did not decrease with disturbance because of increased species: individual ratio. Thus, HD site demonstrated a low species: individual ratio. The k-dominance curves for the communities from the various sites do not overlap and hence reveal changes in the diversity patterns with restoration of degraded mine sites. The most diverse community represented by the lowest curve was recorded at the reference site. Higher butterfly diversity and richness was found for reference and LD sites (Fig. 6) in comparison to the HD and MD sites. The results demonstrate that many species such as *Ixias pyrene, E. hecabe, P. demoleus* and *P. polytes* are very sensitive to disturbance regimes since they were found to be absent in the highly disturbed as well as moderately disturbed sites. Most butterfly species preferred the LD and reference sites this may be because it is known that plant diversity and host plant availability are known to influence butterfly diversity and abundance [38]. Our results show that the vegetation cover and diversity increased progressively with the age of mine site from HD to LD sites (Fig. 1). Hence LD and reference sites, support higher number of specialist species (Table 2).

Correspondence analysis reveals that the butterfly family Nymphalidae has a strong association with the highly disturbed site and therefore it appears to be disturbance tolerant. Our results support earlier reports of higher diversity and abundance of Nymphalidae in a disturbed forest in comparison to natural forests site [39]. We also find that members of Pieridae and Papilionidae families prefer the least disturbed sites and hence appear to be more sensitive to mine site disturbance. In our study *P. demoleus* was found in areas with mature plants which apparently provide a more humid habitat since this species reportedly exhibits mud puddling behaviour to meet its salt and protein requirements [40]. Many of the host plant related requirements of specialist species may be met only at MD and/or LD sites with more diverse and mature vegetation. For instance *E. hecabe* prefers compound leaves of the seedlings of *Acacia mangium* but not of the mature plant as larval food [38]. Hence their preference for LD and reference sites (with mature trees and there by potential to provide seeds for the emergence of new seedlings) may be based on the larval host plant preferences. The presence of the Lycaenid butterfly, *F. trochylus* at the LD and reference sites may be on account of its narrow food preferences [41].

The generalist *P. brassicae* and *C. pyranthe* of family Pieridae were found across all the 3 categories of mine sites. They are found in a wide variety of microhabitats, show mud puddling behaviour, are highly active during the hot period of the day and they have been also reported to visit plants such as *Cassia fistula* and *Cassia grandis* [41, 42]. Our study shows that, family Nymphalidae outnumbered the other families in terms of the number of species. *Danaus genutia* and *D. chrysippus* feeds on nectar of wide variety of commonly found weeds such as *Euphorbia hirta*, *Calotropis gigantea* and the invasive species *Lantana camara* [41] which were recorded at the mine sites in the present study. These species also exhibit high dispersal ability [44]. The success of *D. genutia* and *D. chrysippus* at highly disturbed sites may also be attributed to their unpalatability to many vertebrate predators [45, 46] and successful Müllerian mimicry [47].

Our study supports earlier studies which show that butterfly diversity, abundance and richness decrease with the increase of disturbance intensity in tropical dry forest [28] and also in protected forests [48]. We also find that the distribution pattern of butterfly species along the mine site disturbance gradient is similar to that reported for grasshoppers in an earlier study [49] and ants [50].

5. Conclusion

The present study indicates that butterflies are appropriate subjects for study of the impact of anthropogenic disturbances on insect communities. While mining activity has a negative impact on butterfly diversity and abundance, Revegetation has a clear positive impact on butterflies. Butterfly assemblages composition appeared to be a good predictor of mine site restoration success. While disturbed habitats are preferred by the generalist butterfly species, specialist species such as *I. pyrene*, *E. hecabe*, *C. crocale*, *P. polytes*, *F. trochylus* and *N. hylas* appear to be more vulnerable to loss of natural habitat and green cover.

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