CHAPTER 6: General Discussion

Soil habitat is an important component of terrestrial ecosystem; it contains one of the most diverse assemblages of living organisms known to us. The issues relating to belowground biodiversity (BGBD) are the same as those related to its counterpart aboveground (AGBD). The concealed nature of belowground biodiversity, however, has led less attention being paid to it in the past; especially there is an absence of 'charismatic' species that draw attention.

As mentioned, due to the sheer diversity of soil and soil living organisms, soil biodiversity studies pose many practical difficulties in sampling, identification and interpretation of results. Besides, soil biodiversity is strongly scale dependent, the relation between 'landuse' and 'biodiversity' is much more complex. Losses of natural and semi-natural forests, mostly to agriculture, are a significant concern for biodiversity. On the contrary, the area of intensively managed and human dominated 'working landscapes' are increasing; there is much debate on the implications for biodiversity conservation in these areas. These facts add multiple dimensions to soil biodiversity studies. A 'soil ecosystems approach' with interpretation of biodiversity in terms of soil biological, physical, chemical as well as socio-economic aspect is an ideal solution under such conditions.

Characterization of soil faunal biodiversity with shifting landuse has great significance. Landuse changes (the purpose for and the manner in which biophysical attributes of the earth’s surface and immediate subsurface are manipulated) have great impact on biodiversity. Land-use change is projected to have the largest global impact on biodiversity within 100 years (Sala et al., 2000; Chapin et al., 2000). Though area under forest is reducing with time, biodiversity in managed landscapes gain more attention of conservation value, because as much as 90 per cent of the biodiversity resources in the tropics are located in human dominated or working landscapes (Nair, 2008). Landuse intensification witness extreme events like continuous utilization of same land for years-the permanent agriculture (Giller et al., 1997) at one end to low intensified agroforestry systems with multipurpose tree crops (MPT) at the other end, which have vital role in the tropical biodiversity conservation (Nair, 2008).

Habitat heterogeneity as a function of crop diversification (for eg: agroforestry systems in the tropics) play an important role in increasing the diversity of food resources and environmental conditions for the soil biota while use of pesticides, frequent and/or deep tillage, lack of adequate organic matter management and physical degradation
(erosion, compaction), contamination and pollution etc., play a negative role. From the moment a natural system is modified, major changes occur to the soil environment and to the community present there. The intensity of the change induced and the ability of the various organisms to adapt to these changes will determine the ultimate community present after the perturbation.

During the study, different types of landuse systems with varying land-use intensification were sampled for soil macrofauna. The landuse systems vary in cropping pattern, management inputs and landuse conversion history. This includes pure agriculture at one end to pristine natural forest at another end. The landuse systems sampled represent major ecosystems of the tropics (agriculture, agroforestry, plantations and forests) which facilitate interpolating the results to a broader scale.

Based on the inventory made on the soil macrofauna, 17 higher taxonomic categories (supra-specific taxa) were identified from the study area. The practice of using higher taxonomic groups in environmental monitoring has been developed as an effective tool in the study. As opined by Duelli and Obrist (2003), this tactics facilitated sampling of a large taxonomic spectrum (soil macrofauna) in a large area. Data generated show how the different landuse intensification gradient affects soil macrofauna. Though there was no statistically significant difference in richness of supra-specific taxa across the habitat, the mean number of taxa and the total number of individuals (abundance) was increasing from agricultural systems to natural forest. The result indicated that richness and abundance of soil fauna increased with increasing heterogeneity of the systems and decreasing disturbances. There was ample evidence for spatial patterns affecting the distribution of soil fauna. Fahrig (2003) reviewed the effect of habitat fragmentation on biodiversity and concluded that, fragmentation and habitat loss have increased negative effect on biodiversity. Similar type of observation was also made by Rossi and Blanchart (2005). Changes in landuse affect soil macrofauna (Perner and Malt, 2003). Though there was bias in opinion; habitat heterogeneity affects the abundance and diversity of organisms (González-Megías et al., 2007). The present study indicates that habitat modification have profound negative effect on soil macrofaunal diversity and abundance.

Detailed study on diversity of “representative taxonomic group” (ecosystem engineers) also showed similar pattern like higher taxonomic orders. During the study, 27 species of ants, seven species of earthworms and six species of termites were recorded. Though comparison of total number of species in each group (community composition) is not meaningful, ant diversity was high when compared to the other two groups. Further
analysis reveals that landuse characteristics and related parameters were the main factors which influenced the diversity.

While looking the habitat-wise distribution of these groups, there was a gradual increase in the number of species from intensively managed agricultural systems to less intensively managed agroforestry systems and forests. A popular assumption is that anthropogenic interference results in loss of biological diversity and the most frequently cited example is of agricultural intensification directly resulting in a reduction in biodiversity (Giller et al., 1997). The data also support this hypothesis that land intensification has negative impact on soil macrofauna. Less intensively managed agroforestry systems have more number of ant species than in the forests. Termites and earthworms are more diverse in forest ecosystems. This trend can be explained, because the former group is more mobile than the latter and can easily be colonized in post-disturbed lands. While considering soil nutrient and other parameters, forest soil is more suitable for soft bodied animals like earthworms and termites. Besides, understory vegetation provide excellent niche for ants, while colonization and subsistence of earthworms and termites depend more on soil quality and intensity of disturbance. Land preparation and clearance prevent successful establishment of underground nest by termites and reduce food availability (Black and Okwakol, 1997). In most of the landuse systems studied, such activities are frequent. Earthworm diversity was also confined to natural systems than rest of the habitats. In natural systems, four species were recorded, while in the agriculture system only one species was recorded. Earthworm biodiversity often modified, when natural systems were replaced by agroecosystems, which affects the taxonomic and functional composition (Fragoso et al., 1997). Bhadauria and Ramakrishnan (1991) reported that upon disturbance, native species was replaced by exotic species and succession never resulted in the restoration of native community. Bano and Kale (1991) reported that native species was adapting to agroecosystems and endogeic species is increasing. Similar type of observation was made by Blanchart and Julka (1997) that the disturbed landuse systems have more endogeic as well as peregrine exotic species. In a recent study (Suthar, 2009) from northern part of India reported that, anthropogenic pressure has more influence on earthworm communities. In this study, the total number of earthworm species was just half collected from integrated and organic farming system, indicating the possibility of earthworms as a bio-indicator of good land management. Studies reveal that, exotic species like P.corethrurus can reach a maximum density in disturbed areas (Fragoso et al., 1997). The present study also showed a similar trend, though the total number of species was less.
With respect to individual landuse systems, species richness varied across landuse systems, and lowest richness was observed in coconut monoculture, where fertilizer and pesticide inputs were frequently applied. Highest species richness was observed in landuse systems with minimum disturbances (SEF and MDF). Abundance was also found to be varied with management and disturbance regimes. Increased abundance of species/community itself is an indication of ecosystem sustainability and studies suggest that species abundance model can be used to detect habitat disturbances (Hill and Hamer, 1998).

In the present study, soil macrofauna showed patchy distribution throughout the landuse systems sampled. As opined by Sileshi and Mafongoya (2007), many group of soil fauna showed over dispersion with excess zeros (zero inflation). Out of the many statistical models used, NBD was found to fit well for earthworm, ant and beetles and for termites ZINB was found suitable. Agriculture systems have low abundance of earthworm. Ants, termites, beetles, centipedes, orthoptera and spiders were more abundant in forest ecosystems. Similar observation was also made by many workers (Blanchart and Julka, 1997; Rossi and Blanchart, 2005). As total species richness is an indication, spatial distribution of species across different sites gave a good indication of ability of species to compete and interact (Coleman and Whitman, 2005).

Spatial pattern of soil biota and variability of their densities often regarded as a 'noise' (Ettema and Wardle, 2002). There are many reasons such as resource partitioning, environmental factors, disturbance regimes and intrinsic properties which shape the magnitude of the distribution. Most simply, spatial heterogeneity in soil resources results in microhabitat diversity, which can promote species coexistence through greater resource partitioning. Canonical correspondence analysis was chosen to test the association of soil macrofauna with habitat characteristics. The reason for selecting CCA was that it performs well even if the data is not ideal, with skewed distribution of species, with high 'noise' level, with complex sampling design, and also with non-orthogonal and collinear variables (Palmer, 1993). Besides, it will not create artificial "arch effect" and "tongue effect". The result showed that, CCA performed well in such a situation, and it accounted for greater part of variation (first three axes accounts for 89 per cent of the total variation).

Search for 'variable of importance' (model building) was promising, identified the most important factors shape the soil faunal community. It is meaningless if we consider all the variables, because it is time consuming and questions the model building itself. Interpretation of result is easy only if there are minimum variables, which can be extended to future sampling. In CCA, all the factors would be used for interpreting the variation (full
model). In model building procedure applied here, factors which are more influential are selected by using a forward and backward procedure and final model (reduced model) is selected based on AIC and multicollinearity among the factors. The final model eliminates some variables and remains a few variables. Among 16 variables used in CCA, five variables (phosphorous, pH, calcium, clay and sand content) were remained in the final model and the selected model was significant (p<0.005). Based on this, it was inferred that these parameters are more importance than rest.

It will be more meaningful, if information on total biodiversity of a habitat is available for evaluation of the habitat. It is not pragmatic due to technical difficulties. So it may be better to find out a proxy (species or a community) which can serve as single value for the entire spectrum of biodiversity (Duelli, 1997). To validate the effectiveness of ‘ecosystem engineers’ (ants, earthworms and termites) as a proxy, correlation between the mean number of taxa (higher taxonomic order recorded from each habitat) and mean number of species of ants, termites and earthworms was tested separately. The result (Fig. 6.1) shows positive correlation. Correlation between number of termite species and higher taxa (0.98) and those of earthworm and higher taxa (0.97) found significant, while with ants and higher taxa (0.66) found positive, but not significant. This information was crucial and extends the possibility of termite and earthworms as a surrogate for the diversity of the entire soil macrofauna.

![Fig. 6.1. Correlation between mean numbers of higher taxa with ecosystem engineers across different habitat studied](image-url)
Inventorying entire macrofaunal components in the soil is time consuming as well as expensive with technical problems of getting the identity at species level. Classifying them to coarse taxonomic resolution is more or less easy. On the contrary, sampling and identification of ants, termites and earthworms are comparatively easy. These groups are more or less well studied, taxonomically interesting and abundant and have distinct ecology and trophic requirements. They also can serve as sensitive indicator of habitat perturbations and anthropogenic disturbances. They are often designated as ecosystem engineers due to their ability to modulate other organisms living in soil. Thus, if information on these groups is available, it may serve as base data on the belowground biodiversity, either in local or at landscape level.

The structural heterogeneity produced by plants and associated changes in abiotic gradients can shape the size and heterogeneity of the habitat (Dauber et al., 2005; Eggleton et al., 2005). Though, habitat heterogeneity contributes to maintain diversity, evidence for influence of local scale heterogeneity (e.g., plot level) on soil invertebrate community is less known (Vanbergen et al., 2005). Their studies indicate that soil fauna richness in turn was more in landscape with a mosaic of habitats. Individual fauna may be correlated with local scale habitat variables; overall habitat structure provides, as in the present study, a good refuge for soil fauna.

Agroforestry and monoculture plantations (to some extend) would be better areas for conservation of not only of aboveground biodiversity, but also of belowground biodiversity. This has great significance in the context of depletion of pristine habitat and accelerated landuse conversion. Agroforests are more complex systems, have greater resource capture and utilization efficiency. At landscape or watershed levels, such systems can provide connectivity with forests and help to achieve desired ecological services such as protection of wild habitat and water and soil quality (Garrett et al., 2000; Nair et al., 2008). Secondary forests and tree plantations are of particular importance for biodiversity conservation as their coverage is rapidly expanding in the tropics (Barlow et al., 2007). Conceptually, and also based on the result obtained, the sampled habitats are represented in terms of production/conservation aspects (Fig. 6.1).
Fig. 6.1. Categorization of selected habitat for biodiversity conservation/production value

Agriculture systems aim mainly for production; natural forest aims conservation and protection of wild habitats and biodiversity. Agroforestry and plantations are placed intermediate. Multi-purpose tree crops in the agroforestry and less management intensity enhance its value in both conservation and sustainable production. Studies indicate that plantation forests can provide habitat for a wide range of native forest plants, animals and fungi (Brockerhoff et al., 2008).