Review of Literature
REVIEW OF LITERATURE

Elevational gradient studies with different model organisms date back to the origin of biogeography. A modern resurgence of these interests are likely to contribute important insights for developing a more general theory of species diversity. Fragmented ecosystems, biodiversity loss at alarming rate are the outcome of growing anthropogenic activities in natural ecosystems. Thus, it has become an issue of concern for scientific community. Measurement of ecosystem health is tedious topic and subject to many opinions. In this context, the organisms which constitute an ecosystem, encapsulate all aspects of their environment are generally genuine indicators of perturbations and act as functional groups. With this backdrop the present problem was designed with ants as model organism and to supplement the above stated generalisation the already existing inputs were thoroughly scanned. These inputs have been dealt here section wise to give a more clear and holistic view.

a) Literature pertaining to elevational gradient studies:

Wheeler (1917), Weber (1943) and Gregg (1963) while computing mountain ants of North America, Sudan and Colorado respectively observed ants at high elevations above 2000 meters.

According to Hutchinson (1959), Preston (1962a & b), Connell and Orians (1964), MacArthur (1965, 1969, 1972), Brown and Lomolino (1998) and Sanders (2002) there are two general predictions of how species richness and elevation are related: either species richness decreases monotonically with increasing elevation or richness peaks at mid elevations due to increase in productivity.

Bernstein (1979) investigated the species diversity in ant communities. Rahbek (1995) while studying the elevational gradients of species richness emphasized on the importance to discriminate
between patterns reflecting recent diversification and those reflecting long-term accumulation of species. He further added that other factors such as variation in steepness, geological perturbations, alterations of precipitation patterns etc. should also be taken into consideration.

Stevens (1992) worked on the application of Rapoport’s latitudinal rule to altitude. He pointed that “Rapoport’s latitudinal rule can be extended to elevational distribution of species. Lowland areas with high species richness, species can be characterised as being composed of species with small altitudinal ranges. Highland habitats support species whose altitudinal ranges are larger. The origin of these differences is probably based in the challenges organisms face in coping with extremes of temperature, precipitation and associated climatic conditions at different elevations”.

Rohde (1996) contradicted Stevens (1992) and proposed that Rapoport’s rule should only be applied to study species diversity in Palaearctic and Nearctic regions and that too above an latitude of 40-50° N.

Fellowes (1996) analysed community composition of Hong Kong ants with respect to spatial and seasonal patterns.

Fisher (1996a & b, 1997, 1998, 1999, 2002) worked on ant diversity patterns along an elevational gradient in Madagascar and RNI d’Andringitra. He concluded that species richness is peaked at mid-elevation and it could be the result of the mixing of two distinct, lower and montane forest ant assemblages.

Samson et al. (1997) surveyed ant communities along an elevational gradient in the Philippines extending from lowland dipterocarp forest (250 meters) elevation to mossy forest (1750 meters) and observed very few ants at higher elevations in the tropics.

Bruhl et al. (1998) investigated the stratification of ants in a primary rain forest in Sabah, Borneo. They observed dominance of
Myrmicinae (39.9%) followed by Formicinae (31.5%), Ponerinae (11.5%) and Dolichoderinae (10.2%). Later, Bruhl et al. (1999) worked on altitudinal distribution of leaf litter ants along a transect in primary rain forest on Mount Kinabalu. The ant fauna along the gradients included 283 species representing 55 genera. They made sampling at different altitudes (560, 800, 1130, 1360, 1740, 1930, 2025, 2300, 2600 meters above mean sea level). The number of ant species decreased exponentially without evidence of a peak in species richness at mid-elevation.

Ali and Ganeshaiah (1998) attempted to map diversity of ants and root grubs primarily on available data from various institutes of the country (India) and concluded that such maps are immensely important in understanding the biognomy of the country and in designing the conservation plan for the entire country.

Gunsalam (1999) collected about 71 morphospecies of ants belonging to 7 subfamilies during a preliminary survey and assessment of ant fauna of Borneo, Kelabit Highlands Sarawak. His findings show that ant fauna of this region has mixture of ants found in lowland and highland areas.

Yamane and Hashimoto (1999), Noon-anant (2003) and Watanasit (2003), estimated abundance and diversity of ants concluding that a combination of various ant sampling methods yield better results in the evaluation of ant species than a single sampling method.

Sanders et al. (2003) analysed the patterns of ant species richness along elevational gradients in an arid ecosystem. They observed that ant species richness increased linearly with elevation along a third transect and suggested that patterns of species richness based on data from single transect may not generalize to larger spatial scales.
Xu et al. (2001) evaluated ant communities and their species diversity with altitudinal zonation on west and east slope of Gaoligongshan Mountain in China. They observed that with increase in altitude number of dominant species increase at the north and north-middle section of reserve, but decrease at south section.

Watt et al. (2002) investigated the effects of diversity and abundance of ants in relation to forest disturbances in Cameroon. A total of 97 ant species were recorded from the canopy (from approximately 48,500 individuals), more species occurred in a partial manual clearance plot than complete clearance plot and a total of 111 ant species (from 3,650 individuals) were recorded from leaf litter. Species richness was greatest in the two pattern clearance plots, lowest in two complete clearance plots and intermediate most variable in the three unclear forest plots. Despite some local effects by dominant species, their results support the view that deforestation can reduce arthropod species richness.

Araujo and Fernandes (2003) examined the distribution of ants along altitudinal gradients from 800 meters to 1500 meters in southeastern Brazil. They found that species richness of collected ants on vegetation and soil increased with decreasing elevation, this pattern was found for ants collected on the ground in both mesic and xeric habitats.

Robinson et al. (2003) probed wood ant (Formica lugubris) population in Upper Dearne Woodlands, to investigate relationship between ant activity and factors such as light, level, slope and vegetation.

Fisher (2004) employed many methods for collecting ants, including leaf litter sifting, sweeping, yellow pan traps, hand picking etc. to evaluate the diversity pattern of ants in Mount Doudou in South-Western Gabon. During this survey, he recorded a total of 310
species in 56 genera; the highest species richness of ants recorded in Africa till to date.

Schonberg et al. (2004) compared the arboreal ant species richness in primary forest, secondary forest and pasture habitat of a tropical montane landscape. A total of 21 species were collected from primary forest, 20 from pasture habitat and 9 from secondary forest. This study has implications for conservation of tropical montane habitats in two ways. First, arboreal ant species density is reduced if secondary forest replaces primary forest, which increases the chances of extinction among rare species. Second, pasture trees may serve as repositories of primary forest ant communities due to similar tree structure.

Anu and Sabu (2006) analysed leaf litter ants in the Wayanad region of Western Ghats and collected 22 species from 16 genera. Subfamily Formicinae was the highly speciose in evergreen forests. Aenictinae was present only in deciduous forest. Ponerinae was less speciose in shola forests in comparison to their high speciosity in evergreen and deciduous forests.

Hashimoto et al. (2006) explored vertical distribution of ants in a Bornean Tropical rainforest and concluded that vertical movement of ants from the nesting stratum to other strata might have occurred.

Geraghty et al. (2007) evaluated the body size, colony size and range size in ants along elevational and latitudinal gradients to check the effect of Bergmann’s rule (size of organism often increases with latitude and elevation) and concluded that their results do not supplemented Bergmann’s rule in ants.

Grytnes and McCain (2007) in their article on elevational trends in Biodiversity pointed that most commonly observed patterns are: decreasing richness with increasing elevation and a humped pattern with a richness peak at intermediate elevations. Many factors might be important in shaping the richness trends, including
productivity/energy, mid-domain effect (MDE), source-sink dynamics, species-area relationships, heterogeneity and history.

Sanders *et al.* (2007) tried to enumerate the factors that shape elevational diversity gradients in ants. The results indicated that warmer sites support more species as they support more individuals, thereby reducing the probability of local extinction.

Malsch *et al.* (2008) investigated the factors responsible for the declining of ant species richness with increasing elevation in an evergreen tropical rain forest of Mount Kinabalu, Sabah, Borneo. 376 morphospecies, belonging to 65 genera and 8 subfamilies were collected. They observed that decline in species richness is significantly correlated with decline in temperature.

Nogues-Bravo *et al.* (2008) estimated the scale effects and human impact on the elevational species richness gradients. They used an extensive data set comprising 400,000 records covering 3,046 species of vascular plants, lichens & bryophytes. The relationship between species richness and altitude varied greatly with scale of extent. When the entire elevational gradient was surveyed, the pattern was hump shaped, changing progressively to a monotonically decreasing pattern as the scale of extent diminished.

Sabu *et al.* (2008) estimated the diversity of forest litter-inhabiting ants along elevations in the Wayanad region of the Western Ghats. Abiotic factors such as litter temperature, humidity, litter depth, rainfall and slope of the terrain were found to influence abundance and elevational distribution of litter ants. Ant species richness increased from 300 meters to 1000 meters and subsequently decreased, recording a hump-shaped peak at mid-elevations. 29 ant species belonging to 18 genera under 6 subfamilies were recorded during the study.

Zelikova *et al.* (2008) assessed seed dispersal along an extensive elevational gradient (256-2025meters) in great Smoky Mountains
National Park, USA and concluded that seed removal decreases with elevation, but seed dispersal distance was not dependent on elevation. The most important variables predicting seed removals were average annual temperature and the abundance of *Aphaenogaster rudis* both of which varied along the elevational gradient.

Bharti and Sharma (2009) carried preliminary investigations on diversity and abundance of ants along an elevational gradient in Jammu-Kashmir Himalaya. They found that subfamily Myrmicinae is the most abundant (66%), followed by Formicinae 26.81%, Ponerinae 4.84% and Dolichoderinae 2.35%.

Kumar and O’Donnell (2009) quantified the foraging rates of above ground and underground foraging army ants along an elevational gradient from 1090 meters to 1540 meters. The observations revealed that army ants which forage above ground may be restricted to forested area due to a thermal tolerance threshold, but get released from this limitation at higher elevations. Also underground foraging permits some army ants to persist within modified landscapes.

Machac et al. (2010) explored elevational gradient in assessing phylogenetic structure of ant communities. They revealed interplay of biotic and abiotic constraints on diversity. And observed that ant species density is positively related to temperature, so at higher elevations (in cooler conditions), there are fewer species than in warmer, lower elevation sites.

Narendera *et al.* (2010) analysed the structure of ant assemblages in Western Ghats, India and worked out the role of habitat disturbance and introduced species. They sampled 84 species representing 30 genera from 5 subfamilies. Myrmicinae was most widely represented with 44 species and 11 genera, genus *Monomorium* was most rich, represented by 12 species and genus
*Pheidole* was most abundant followed by *Camponotus compressus* and *Diacamma rugosum* was most frequently occurring species.

Longino and Colwell (2011) worked out density compensation, species composition, and richness of ants on a neotropical elevational gradient by sampling seven sites ranging from 50 meters to 2000 meters. They observed that worker density and microsite occupancy were high and relatively constant from 50 meters to 1500 meters and then abruptly dropped to near zero at 2000 meters.

**b) Literature pertaining to ants as bioindicators:**

Greenslade (1978) first proposed functional group scheme based on global scale responses of ants to environment stress and disturbance. Majer (1983) effectively used ants as bioindicators of mine site rehabilitation, land use and land conservation. Andersen and McKaige (1987) assessed ant communities with respect to disturbance at Rotamah island, Victoria. Andersen (1988) applied function group scheme to measure immediate and long term effects of fire on seed predation by ants in Australia. Later, Andersen (1991) evaluated the response of ground-foraging ant communities to three experimental fire regimes in a Savanna forest of tropical Australia and classified ant species into different functional groups based on habitat requirements and competitive interactions, with the most important groups being dominant species of *Iridomyrmex* (11 species); Generalised Myrmicinae (mostly *Monomorium* and *Pheidole*, 22 species); Hot climate specialists (*Melanophorus*, *Monomorium* and *Meranoplus*, 14 species): Cryptic species (13 species) and Opportunists (mostly *Rhytidoponera* and *Tetramorium*, 11 species). The results divulge that ant communities in annually burned plots were dominated by *Iridomyrmex*, hot climatic specialists, opportunists, very low number of generalised myrmicines and cryptic species, thus
clearly demonstrating the effect of fire regimes on most important faunal groups in tropical Savannas; this study deduced important implication for conservation management in these ecosystems.

Majer (1992, 1995) and Majer and de Kock (1992) examined ant recolonisation of rehabilitated bauxite mines of Brazil and South Africa. He observed that ant species richness is built up most rapidly in areas rehabilitated with mixed mata species and least rapidly in areas with *Eucalyptus*.

Andersen (1995 a and b) proposed a classification of Australian ant communities, based on functional groups which parallels plant life-forms in relation to stress and disturbance. He concluded that the classification would identify the structural types of ant communities which vary predictably in response to stress and disturbance, thus would provide a general framework for the analysis of ant community structure, integrating the role of both biotic and abiotic factors.

Read (1996) deliberated on the use of ants to monitor environmental impacts of salt spray from a mine in arid Australia, observed that ant communities may respond quickly to environmental stress, thus could be used to monitor the effectiveness of remediation and environmental rehabilitation measures.

Andersen (1997a and b) compared the functional groups and patterns of North-American ant communities with Australia. He noticed that almost all North-American taxa can be matched with what appears to be ecological equivalent taxa in Australia and biogeographical patterns of functional group composition are broadly similar across the two countries.

Andersen (1997c) suggested that a taxon’s actual performance as an indicator depends on its ability to reflect the responses of a wide range of ecosystem processes and components.

Folgarait (1998) reviewed the information available on ant biodiversity patterns, how it can be quantified, and how biodiversity is
affected by human impacts such as land use change, pollution, invasions and climatic change.

King et al. (1998) analysed biogeographical patterns of ant community structure and the responses of ant communities to disturbance. They observed that habitat disturbance favoured opportunists, representing about 80-95% of total ants in traps at disturbed sites as compared to 40% of the total ants at undisturbed sites.

Lawtan et al. (1998) examined the biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. They found that attempts to assess the impacts of tropical forest modification and clearance using changes in the species richness of one or a limited number of indicator taxa (including popular groups such as birds or butterflies) to predict changes in richness of other taxa may be highly misleading, as different kinds of organisms have very different ecological requirements, thus are extremely unlikely to show similar responses to even major changes in habitat.

Nash et al. (1998) monitored changes in stressed ecosystems using spatial patterns of ant communities. Analysis of spatial patterns of selected ant genera demonstrated that some genera respond to soil surface changes resulting from live stock grazing (Solenopsis), some respond to changes in composition and structure of vegetation (Conomyrma) and some are resistant to the short-term changes resulting from grazing and vegetation manipulation (Pogonomyrmex).

Majer and Nichloas (1998) worked for 14 years on recolonization patterns of ants in Western Australian rehabilitated bauxite mines with reference to their use as indicators of restoration success. The results confirmed that in the first 2 years of succession, seedlings with mixed species result in more rapid attainment of forest like ant fauna and in last 6 years of study ant fauna of the planted plot had become more similar to that of seeded plot.
Andersen (1999) provided usefulness of ants as indicators.
Bisevac and Majer (1999) conducted a survey in seven rehabilitated (2 to 20 years old) in three native heathland reference sites in Western Australia. They generalised that rehabilitation allows for a rapid return of ant species, and even after twenty years the fauna still had not attained the composition as the original heath fauna.

Andersen (2000 a and b) again emphasized on the importance of functional group scheme for measuring ecosystem health.

Read and Andersen (2000) further used ants as early warning indicators.

Hoffmann et al. (2000) studied the impact of dry deposition of SO$_2$ emissions on ant abundance, diversity and composition in semi-arid tropics of Northern Australia. Ant abundance and species richness was observed to be lowest in high and medium sulphur zones thereby clearly indicating that ants are sensitive to SO$_2$ emissions, have potential as good candidates to act as indicator group.

Floren et al. (2001) evaluated that how the anthropogenic disturbances change the structure of arboreal tropical ant communities by sampling 273 species of Formicidae, 195 (71.4%) in a primary forest and another 78 (28.6%) species in a secondary forest. They observed that while clearing of a primary forest for agricultural use, its arthropod communities are completely disturbed, if such areas are abandoned and left to natural succession, arthropod communities also show a succession with respect to the composition on the order, diversity and community structure levels.

Andersen et al. (2003) used ants as indicators at mine site restoration in central Queensland.

Hoffmann and Andersen (2003) investigated the response of ants in relation to ecosystem disturbances in Australia, with particular references to functional groups. They found that functional
group scheme can provide a useful predictive framework for assessing ant community response to disturbance, when such disturbances cause marked changes in vegetation structure.

Gomez et al. (2003) analysed the structure of ground-dwelling ant assemblages in relation to land use change in the north-western Mediterranean region.

Andersen and Majer (2004) discussed in detail the importance and effectiveness of ants as bioindicators in land management in Australia. They stated that ants are usually abundant, diverse and ecologically important, they are prominent components of most of the world’s terrestrial ecosystems. Ants can act valuable focal group for monitoring invertebrate biodiversity and as bioindicators in land management.

Diehl et al. (2004) analysed ground-dwelling ant fauna of sites with high levels of copper and observed that the control site was the richest in ant species; whereas sites with high level of copper and poor cover presented lowest richness.

Ottonetti et al. (2006) investigated recolonization patterns of ants in a rehabilitated lignite mine in Central Italy to assess the potential for the use of Mediterranean ants as indicators of restoration process. They found ants to be suitable tool for biomonitoring, due to their ability to respond to environmental changes related to restoration process. The functional group approach proved to be a valuable framework to better interpret local trends in terms of global ecological patterns of ant communities.

Nakamura et al. (2007) scrutinized the role of ants and other soil arthropods as bioindicators of the impacts of rain forest clearing and subsequent land use. They generated ‘composite indices’ to evaluate the potential of arthropod taxa as bioindicators.

Ribas and Schoeredr (2007) evaluated ant communities, environmental characteristics and their implications for conservation
in the Brazilian Pantanal and observed that response of ant community can reflect human impacts on the forests.

Savitha et al. (2008) observed the response of ants to disturbance gradients in and around Bangluru, India and estimated that ant species richness and abundance was higher in the disturbed site. Common species increased with disturbance, urbanization has differential effects on various taxa depending on their dispersability and adaptability to human settings. Therefore, existing green areas must be protected on priority basis and more sites must be developed with native vegetation to enhance biodiversity.

Andersen et al. (2009) observed the rehabilitation of Eucalyptus forest of South-eastern Australia with ants as indicators.

Bennett et al. (2009) examined the spatial fidelity in the pattern in species richness, abundance and composition of ants, birds, mammals and reptiles in a Eucalyptus vegetation type in Australian tropical Savanna woodland. The study suggested that highly divergent species group (e.g. invertebrates vs vertebrates) do not pattern in a complementary way to local scale disturbance. Instead it advocated that complimentary indicator species should be sampled that are sensitive to the impact of concern and the surrogates chosen should represent a variety of ecosystems, landscapes, plants plus animals of interest.

Crist (2009) reviewed biodiversity, species interactions and functional roles of ants in fragmented landscapes and analysed that shifts in ant species composition, relative abundance due to habitat fragmentation have direct and indirect effect on species interactions of ants, including sap feeding insects, seed dispersers and vertebrate mutualists. The loss of some ant species from small habitat fragment may have widespread effect in ecosystems because of their functional role as keystone mutualists.
Hernandez-Ruiz et al. (2009) assessed the composition and functional groups of epiedaphic ants in irrigated agroecosystem and in non-agricultural areas in Central Mexico.

Maleque et al. (2009) investigated the role of arthropods as indicators of sustainable forest management, with a focus on plantation forests. They found that different arthropod groups respond differently to forest management. Ants, carabid beetles and spiders respond to local-scale disturbance-induced vegetation development caused by thinning and can be used to infer the ecological suitability of forest management treatments.

The above cited literature clearly indicates that no such study has ever been carried on Himalaya, which is currently subject to great deal of anthropogenic activities and is listed as fragile. So, the present endeavour is the first attempt which would probably have higher impact on further ecological and conservational approaches.
c) Books relevant to the study:
Holldobler, B. and Wilson, E.O. (1990): The Ants
Mani, M.S. (1962): Introduction to High Altitude Entomology
Mani, M.S. (1968): Ecology and Biogeography of High Altitude Insects
Wadia, D. N. (1975): Geology of India