SOIL MESOFAUNA OF DACHIGAM NATIONAL PARK IN KASHMIR HIMALAYA

Aamir Bin Masood and Ashok K. Pandit
P.G.Department of Environmental Science, University of Kashmir, Srinagar - 190006, J & K, India

ABSTRACT

Soil mesofauna was studied under different vegetal types of Dachigam National Park – Pine forest, Parrotia forest, Riverive forest and Grassland. The mesofauna groups studied were Acari, Collembola, Diplura and Symphyla. Acari was found to be the most abundant group contributing far more than 50% of the mesofauna at all the sites. Collembola was the next most abundant group. Sites Parrotia forest and grassland exhibited the highest degree of similarity. On the whole all the groups showed positive correlation with organic matter and moisture content of the soil and negative correlation with pH. The mesofauna resembled that of the temperate world.

Key Words: Soil, mesofauna, Acari, Collembola, Diplura, Symphyla.

INTRODUCTION

One of the most important natural resources that cover much of the earth's land surface is soil. Although not generally visible to the naked eye, soil is one of the most diverse habitats on earth and contains one of the most diverse assemblages of living organisms (Giller *et al*., 1997). Nowhere in nature are species so densely packed as in soil communities (Hagvar, 1998). The soil fauna has been described as the "poor man's rainforest" (Usher *et al*., 1979; Giller, 1996). Many modern soil biologists consider the soil fauna to be the last biotic frontier by its sheer numbers, diversity of species, difficult taxonomic compositions and numbers of undescribed species (Andre *et al.*, 1994).

Soil animals have been classified into three categories – microfauna, mesofauna and macrofauna, depending on size (Wallwork, 1970; Swift *et al.*, 1979). Soil mesofauna, also called meiofauna, range from 0.1 to 2mm in diameter and includes all microarthropods, as mites (Acari), springtails (Collembola), bristletails (Diplura), symphylans (Symphyla) and enchytraeids. Among these, mites and springtails often dominate. Soil mesofauna have limited burrowing ability and generally live within the soil pores. They may feed upon microflora (algae, bacteria, cyanobacteria, fungi, yeasts, myxomycetes and actinomycetes), decaying plant material and other soil invertebrates (Lawrey, 1987).

Compared to the soil physico-chemical study, soil biology has been least studied, particularly when it comes to soil mesofauna. Considering the density and diversity of soil mesofauna in soil ecosystem, great emphasis needs to be given to the study of the soil fauna in general, and soil mesofauna in particular. Qualitative and quantitative studies of soil fauna, particularly the micro-arthropods (mesofauna) from Indian soils began from the mid-sixties. However, major contributions have been from the agricultural fields, grasslands, abandoned fields and tea gardens, and very few from the forests, particularly the Himalayan forests. The microarthropod studies from various forest floors of India include those of Banerjee (1972), Hazra (1978), Mir (1986), Annadurai *et al.* (1988), Reddy and Reddy (1996), Bisht and Chattoraj (1998), etc.

During 2004, the students of P.G. Department of Environmental Science conducted the study on different aspects of the ecology of the Dachigam National Park. In the present paper, the density and structure of soil mesofaunal community under various vegetal types of the National Park and the effects of various soil parameters on different groups of mesofauna other than Enchytraeids and insect larvae are described.

STUDY AREA AND STUDY SITES

The study was conducted in Dachigam National Park (Fig. 1).

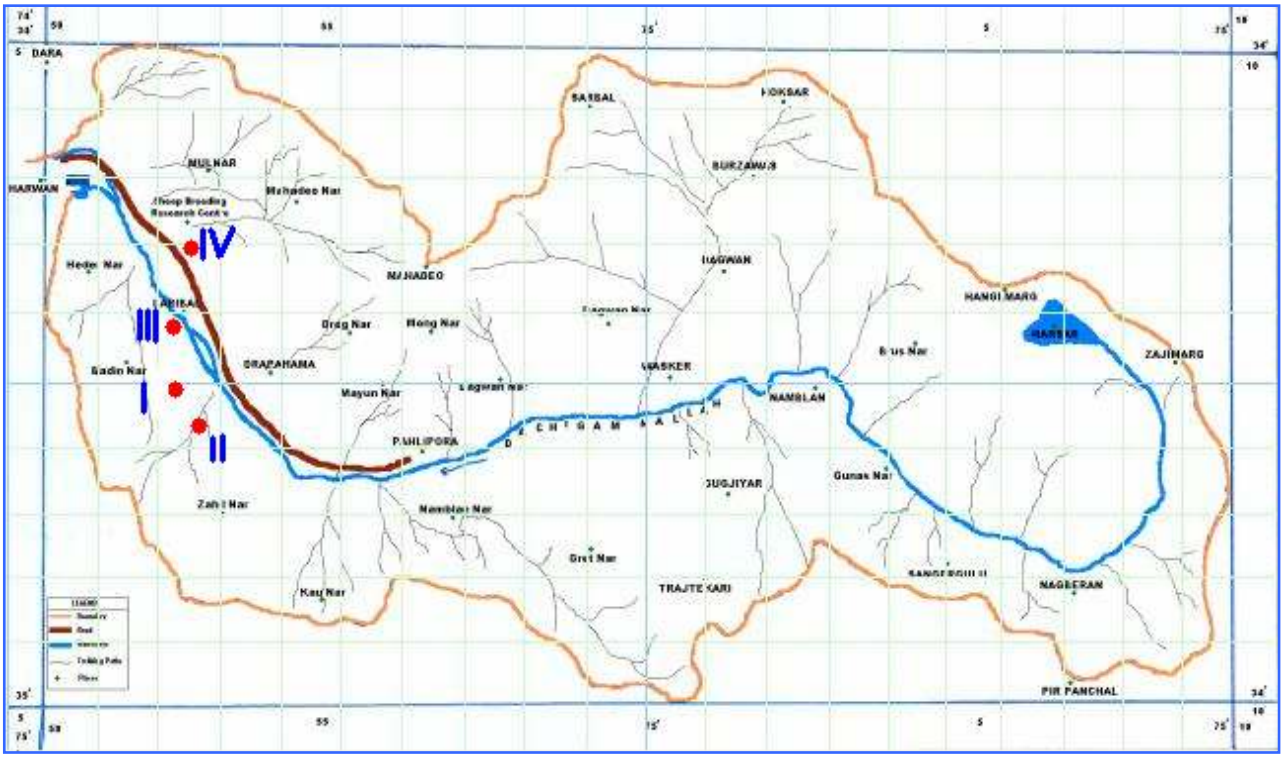


Fig. 1. Map of Dachigam National Park showing the four study sites

Dachigam National Park is located about 22 kilometers northeast of Srinagar, the capital city of Jammu and Kashmir, covering an area of 141 km². It is situated between 34°04′ and 34°11′ N latitude and 74°54′ and 75°09′ E longitude.

Since the national park is home to a variety of ecosystems, it was important, therefore, to choose those sites for the study that represent the mesofaunal diversity of the maximum area of the park. Based on the same ideology, four study sites were selected, which represent the four major vegetal types of the park:

Site I

Site I was a north-facing coniferous forest (Plate I). *Pinus wallichiana* is the dominant tree at this site. It is situated about 1km south-east of Badin Nar. Coniferous forest soils are black in colour with rich organic matter.

Site II

Site II was a north-facing deciduous forest (Plate II). *Parrotiopsis jacquemontiana* is the dominant tree at this site. It is situated about 1.5km south-east of Badin Nar. Parrotia stand

soils are brownish-black in colour with rich organic matter.

Site III

Site III was a north-facing Riverine forest (Plate III). The dominant vegetation at this site comprises of *Aesculus indica, Celtis australis, Salix wallichiana, Morus alba* and *Rhus* sp. It is situated adjacent to the wooden bridge adjacent to Laribal Fish Farm. Riverine forest soils are generally wet and brownish-black in colour.

Site IV

Site IV was a south-facing protected Grassland (Plate IV). The dominant vegetation at this site comprises of *Themeda anathera, Poa* sp. and *Stipa siberica.* It is situated alongside the road leading to Sheep Breeding Farm. Grassland soils are having fine texture, usually sandy and light-brownish in colour.

Material and Methods

Sampling was carried out on monthly basis for a period of six months from June to November 2004. Two (10 × 10 × 10) cm soil samples were taken randomly at each site for each month with the help of a soil-corer.

Mesofauna was extracted by using modified Berlese-Tullgren funnels. Each undisturbed sample was inserted into the funnels and the fauna got extracted separately through a mesh in the funnel and eventually got collected into glass jars kept beneath the funnels, containing 70% ethyl alcohol. After extraction, the organisms were preserved in freshly prepared 70% ethyl alcohol solution. They were kept in the preservative for at least 2 weeks before examination under a microscope (Christiansen and Bellinger, 1998).

The preserved specimens were sorted out, counted and identified under a stereoscopic binocular microscope. Identification of the specimens was carried mostly up to the generic level using keys and illustrations provided in Baker and Wharton (1952), Evans *et al.*(1967), Balogh and Mahunka (1983), Norton (1990), Woolley (1990), Balogh and Balogh (1992), Christiansen and Bellinger (1998), as well as comparing them with those already identified by Mir (1986) and Bhat (1987). Population density, relative abundance, Sorensen's quotient of similarity and Pearson's correlation coefficient were calculated for the recorded data.

Results

(1) Faunistic Composition of Soil Mesofauna

A total of 36 genera were recorded from the four sites during the study period of which 19 genera belonged to Acari (9-Mesostigmata, 6-Prostigmata and 4-Mesostigmata), 10 to Collembola, 4 to Diplura and 3 to Symphyla in a decreasing order. There were significant variations in the number of genera recorded at four different sites. 29 genera (15-Acari, 8-Collembola, 4-Diplura and 2-Symphyla) were recorded at Site I (Table 1). 25 genera (13-Acari, 7-Collembola, 3-Diplura and 2-Symphyla) at Site II, 28 genera (15-Acari, 8-Collembola, 3-Diplura and 2-Symphyla) at Site III and 21 genera (10-Acari, 6-Collembola, 3-Diplura and 2-Symphyla) at Site IV was the composition at the three other sites.

(2) Population Density

The complexity and abundance of soil mesofauna was found to be greater in soils with a thick litter cover. The population density of mesofauna was found to vary from site to site and from month to month throughout the study period. Acari was the most dominant group at all the sites. Collembola followed it as the second most abundant group for all the sites. It was followed by Diplura for Sites I and III and by Symphyla for Sites II and IV (Table 2).

The major proportion of the Acari population was made up by the genera like *Scheloribates, Galumna, Belba, Oppia, Smaris*

and *Petrobia.* In Collembola, the largest contributors to the total Collembola

Table 1: Site-wise distribution of various mesofaunal genera recorded during the study period

Mesofaunal Group	Site I	Site II	Site III	Site IV
Acari	*Scheloribates* *Galumna* *Belba* *Archegozetes* *Gamasina* *Hermannia* *Oppia* *Asca* *Veigaia* *Gamasipus* *Rhagidia* *Petrobia* *Eupodes* *Linopodus* *Smaris*	*Scheloribates* *Galumna* *Belba* *Epilohmannia* *Hermannia* *Oppia* *Asca* *Gamasipus* *Amblysius* *Anystis* *Petrobia* *Smaris* *Eupodes*	*Scheloribates* *Galumna* *Belba* *Archegozetes* *Epilohmannia* *Allonothurus* *Oppia* *Asca* *Veigaia* *Amblysius* *Rhagidia* *Eupodes* *Petrobia* *Anystis* *Smaris*	*Scheloribates* *Galumna* *Belba* *Epilohmannia* *Oppia* *Asca* *Gamasipus* *Rhagidia* *Eupodes* *Anystis*
Collembola	*Hypogastrura* *Entomobrya* *Isotoma* *Onychiurus* *Folsomia* *Orchesella* *Tomocerus* *Friesea*	*Hypogastrura* *Entomobrya* *Onychiurus* *Folsomia* *Orchesella* *Tomocerus* *Lepidocyrtus*	*Hypogastrura* *Entomobrya* *Onychiurus* *Folsomia* *Orchesella* *Tomocerus* *Tulbergia* *Friesea*	*Hypogastrura* *Entomobrya* *Onychiurus* *Folsomia* *Tomocerus* *Lepidocyrtus*
Diplura	*Anajapyx* *Heterojapyx* *Metajapyx* *Campodea*	*Anajapyx* *Heterojapyx* *Campodea*	*Anajapyx* *Heterojapyx* *Campodea*	*Anajapyx* *Heterojapyx* *Campodea*
Symphyla	*Scutigerella* *Symphylella*	*Scutigerella* *Symphylella*	*Scuitgerella* *Scolopendrella*	*Scutigerella* *Symphylella*

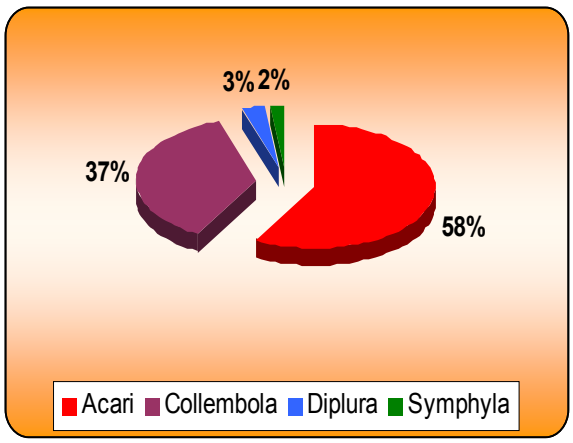
Table 2: Population density of mesofauna (individuals/m^2) at the four study sites during the study period

Mesofaunal Group	Site	June	July	Aug	Sep	Oct	Nov
Acari	I	2200	2550	2600	2850	3450	2400
	II	2200	2300	2200	2600	2200	1700
	III	3150	3050	2750	2600	2500	2850
	IV	1950	2150	2150	1750	1600	1150
Collembola	I	1550	1500	1650	1850	2200	1350
	II	1600	1550	1650	1800	1650	1300
	III	2400	1950	2100	2050	1700	2100
	IV	850	1150	1200	1000	900	650
Diplura	I	100	150	200	100	150	50
	II	150	300	250	250	150	50
	III	450	450	250	400	150	100
	IV	150	150	250	200	150	100
Symphyla	I	100	200	150	50	50	-
	II	200	250	350	350	200	100
	III	250	400	400	350	300	50
	IV	200	250	350	350	200	150

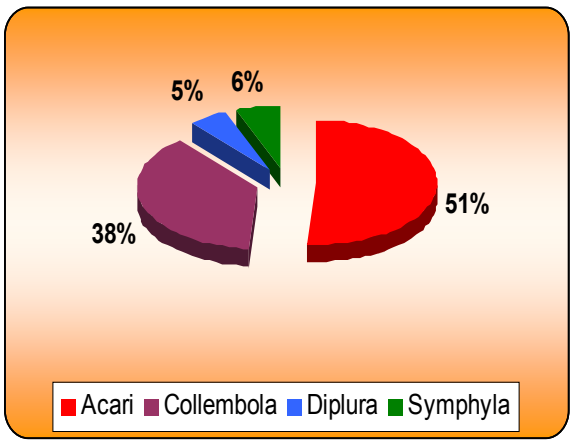
population were *Hypogastrura, Entomobrya, Folsomia, Tomocerus* and *Onychiurus.* In case of Diplura and Symphyla, all the genera contributed almost equally to the overall population.

(3) Relative Abundance

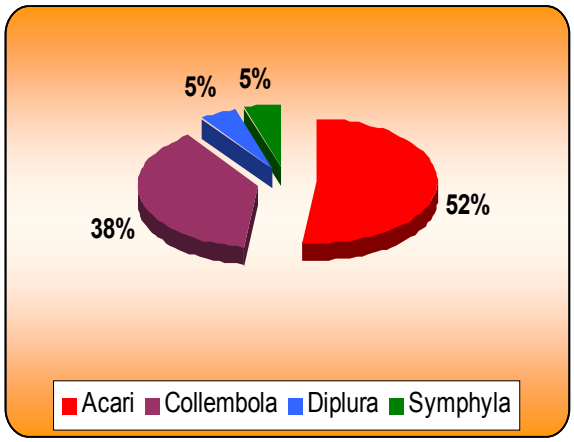
The contribution of various mesofaunal groups to the total mesofaunal population depicted different trends at different sampling sites [Fig. 2(a-d)]. The mean monthly relative abundance (MMRA) of different mesofaunal groups was also calculated for all the Sites. For Site I, the MMRA for Acari was 58%, followed by Collembola (37%), Diplura (3%) and Symphyla (2%) in a decreasing order. At Site II, the MMRA for Acari was 51%, Collembola (38%), Diplura (5%) and Symphyla (6%). At Site III, the MMRA for Acari was 52%, Collembola (38%) and 5% each for Diplura and Symphyla. At Site IV, the MMRA for Acari, Collembola, Diplura and Symphyla was 57%, 30%, 5% and 8% respectively.



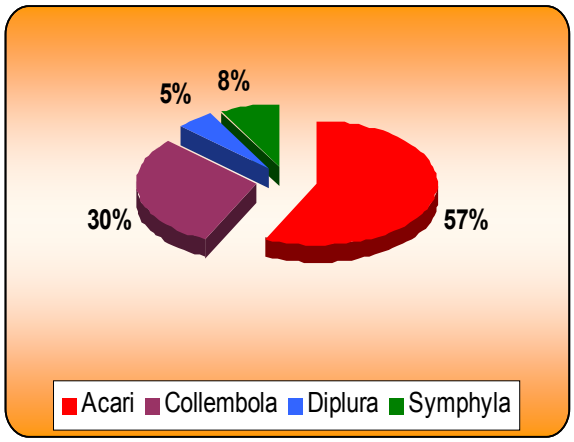
(a)



(b)



(c)



(d)

Fig. 2(a-d). Mean monthly relative abundance of different mesofaunal groups at Sites I, II, III and IV respectively

(4) Quotient of Similarity

This parameter was used to determine the degree of similarity of mesofauna collected from different sites. On the whole, the highest similarity (86.95%) was shown by Parrotia forest and grassland, whereas the least similarity (72.0%) was exhibited by Pine forest and grassland (Table 3).

Table 3: Quotient of Similarity values (%) for different mesofaunal groups for all the site combinations

Mesofaunal Group	Sites I and II	Sites I and III	Sites I and IV	Sites II and III	Sites II and IV	Sites III and IV
Acari	71.42	73.33	64	78.57	78.26	72
Collembola	80	87.5	71.42	80	92.30	71.42
Diplura	85.71	85.71	85.71	100	100	100
Symphyla	100	50	100	50	100	50

(5) Correlation with Some Soil Parameters

Three soil parameters viz. pH, organic carbon and moisture content are thought to greatly influence the density and diversity of soil mesofauna (Badejo *et al.*, 1998; Huhta and Hanninen, 2001; Cassagne *et al.*, 2003). Soil mesofaunal groups were correlated with these three soil parameters, the data for which was provided by Khan (2005). The results obtained are presented in Table 4. Acari showed a negative correlation with pH except at Site III, a positive correlation with organic carbon at all the sites and a positive correlation with moisture content except at Site IV. Collembola showed a negative correlation with pH except at Site III and a positive correlation with organic carbon and moisture content except at Site IV. Diplura showed a negative correlation with pH except at Site III, a positive correlation with organic carbon except at Site IV and a positive correlation with moisture content at all the sites. Symphyla showed a negative correlation with pH except at Site I, a positive correlation with organic carbon and with moisture content at all the sites.

DISCUSSION

The mesofaunal groups studied were Acari, Collembola, Diplura and Symphyla. Acari and Collembola were the most dominant groups contributing 87-95 % of all the mesofauna. Among mesofaunal groups, Acari and Collembola are the most abundant organisms in the soil, as reported by Rusek (1998), Noti *et al.* (2003) and Irmler (2004). The mesofauna resembled that of the temperate world. The mesofauna of all the sites showed some degree of similarity, as the QS values for all the site combinations were greater than 50%. Similar findings have been obtained by Heneghan *et al.* (1998), while working on the microarthropod community structure in tropical and temperate sites.

Table 4: Correlation between mesofaunal groups and some soil parameters

Mesofaunal Group	pH				Organic Carbon (%)				Moisture Content (%)			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Acari	-0.58	-0.42	0.59	-0.38	0.73	0.62	0.58	0.61	0.57	0.71	0.62	-0.21
Collembola	-0.62	-0.64	0.43	-0.63	0.69	0.61	0.71	-0.32	0.62	0.74	0.60	-0.17
Diplura	-0.40	-0.44	0.41	-0.28	0.56	0.53	0.54	-0.22	0.21	0.31	0.73	0.33
Symphyla	0.37	-0.32	-0.36	-0.33	0.54	0.49	0.51	0.20	0.56	0.42	0.58	0.35

The variations were encountered in the population densities of different mesofaunal groups at different sites during the study period. The populations were found to be highly influenced by the soil parameters like pH, organic carbon, moisture content, temperature, etc. The population numbers of the mesofaunal groups varied during different months. The highest population density of mesofauna during October at Pine forest site may be attributed to the fact that litter fall and consequent humus production during this period is very prominent, thereby making the soil rich in organic matter. mesofauna are known to be litter feeders, and thus flourish in number with increasing organic matter (Webb, 1994; Heneghan and Bolger, 1998; Irmler, 2000; Reynolds *et al.*, 2003). Same may be the reason for the highest density of mesofauna in September at Parrotia forest site. The type of litter was also found to influence the density of mesofauna. A higher faunal abundance in mixed-species litter than in those with single-species litter was recorded, which was supported by the findings of Kaneko and Salamanca (1999). Mesofaunal groups were found to be positively correlated with soil organic matter at both these sites. Thus an increase in the soil organic carbon during this part of the year leads to an increase in the population density of the mesofauna.

The highest population density of mesofauna in the month of June at Riverine forest site may be attributed to the combined effect of high moisture content and soil temperature during this period, as mesofaunal groups were significantly positively correlated with the moisture content of the soil, which was supported by the findings of authors (Huhta and Hanninen, 2001; Lenoir *et al.*, 2003; Tsiafouli *et al.*, 2004). Mesofaunal groups were found to be negatively correlated with soil pH except at Riverine forest site. This may be due to the high moisture content in these soils, which is supported by the works of Jandl *et al.* (1997) and Huhta and Niemi (2003). At grassland site, the highest mesofaunal density was recorded in

August which may be attributed only to the optimum temperature during this part of the year, because other factors as moisture content and organic carbon content were seen to be less significant for this site. Similar findings have been reported in case of grasslands by Coulson *et al.* (1996), Badejo *et al.* (1998), Huhta and Hanninen (2001). Less vegetation cover at this site compared to the other sites may also be one of the reasons for less mesofaunal density and diversity. Further the grassland is grazed upon by the sheep of the nearby Sheep Breeding Farm (Dachigam), which also tends to reduce the mesofauna population numbers, as supported by the works of Kay *et al.* (1998) and Peterson *et al.* (2004).

In November, the lowest mesofaunal density was recorded at almost at all the study sites. This can be attributed to the seasonal migration, which mesofauna are known to show in response to the cold temperatures and other changing environmental factors. The migrations can be vertical or horizontal depending upon the severity of the changing environmental conditions (Hattar *et al.*, 1992; Laakso *et al.*, 1995). Some genera of all the four mesofaunal groups were recorded at all the study sites. The abundance of these genera may be due to their better adaptability to the diverse kinds of habitats/environmental variables.

ACKNOWLEDGEMENTS

This article forms a part of the M.Sc. project work of the first author. The authors are highly thankful to the Chief Wildlife Warden, Department of Wildlife Protection, J & K State for granting permission to work inside the national park. Thanks are also due to the Head, P.G. Department of Environmental Science for laboratory facilities.

REFERENCES

Andre, M. H., Noti, M. I. and Lebrun, P. 1994. The soil fauna: the other fast biotic frontier. *Biodiversity and Conservation*. **3**: 45-56.

Annadurai, R. S., Chandrasekhar, S. S. and Balu, A. 1988. Trophic structure and diversity in some litter inhabiting microarthropods of monoculture and natural forest ecosystems. *Proc. of Indian Academy of Sciences*. **97**: 301-308.

Badejo, M. A., Tian, G. and Nathaniel, T. I. 1998. Abundance of springtails (Collembola) under four agroforestry tree species with contrasting litter quality. *Biology and Fertility of Soils*. **27** (1): 15-20.

Baker, E. W. and Wharton, G. W. 1952. *An Introduction to Acarology*. New York, **i-xiii**, 1-465.

Balogh, J. and Balogh, P. 1992. *The Oribatid Mites Genera of the World*. Vols.1 and 2. Hungarian National Museum Press, Budapest, Hungary.

Balogh, J. and Mahunka, S. 1983. The soil mites of the world. Vol. 1. *Primitive Oribatids of the Palaearctic region*. Elsevier, New York.

Banerjee, S. 1972. Microarthropods and humus formation. *Journal of Indian Society of Soil Science*. **20**: 403-405.

Bhat, G. A. 1987. *Analysis of animal community in Dachigam Pasturelands*. Unpub. M.Phil. Thesis, The University of Kashmir. Personal communication.

Bisht, B. S. and Chattoraj, A. N. 1998. Distribution of collembolan species at different altitudes and depths in Alaknanda valley of Garhwal Himalayas. *Himalayan Journal of Environment & Zoology*. **12**: 49-53.

Brussaard, L., Behan-Pelletier, V. M., Bignell, D. E., Brown, V. K., Didden, W., Folgarait, P., Fragoso, C., Wall-Freckman, D., Gupta, V. V. S. R., Hattori, T., Hawksworth, D. L., Klopatek, C., Lavelle, P., Malloch, D. W., Rusek, J., Söderström, B., Tiedje, J. M. and Virginia, R. A. 1997. Biodiversity and ecosystem functioning in soil. *Ambio*. **26**: 563-570.

Cassagne, N., Gers, C. and Gauguelin, T. 2003. Relationships between Collembola, soil chemistry and humus types in forest stands (France). *Biology and Fertility of Soils*. **37** (6): 355-361.

Christiansen, K. and Bellinger, P. 1998. *The Collembola of North America, north of the Rio Grande. A taxonomic analysis*. Grinnell College, Grinnell IA.

Coulson, S. J., Hodkinson, I. D., Webb, N. R., Block, W., Bale, J. S., Strathdee, A. T., Worland, M. R. and Wooley, C. 1996. Effects of experimental temperature elevation on high-arctic soil microarthropod populations. *Polar Biology*. **16**(2): 147-153.

Evans, G. O., Sheals, J. G. and MacFarlane, D. 1967. *The Terrestrial Acari of the British Isles: An Introduction to Their Morphology and Classification*. Vol. 1, Dorking: Adlard and Son, Batholomeu.

Giller, K. E., Beare, M. H., Lavelle, P., Izac, A. M. and Swift, M. J. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. *Appl. Soil Ecol*. **6**: 3-16.

Giller, P. S. 1996. The diversity of soil communities, the 'poor man's tropical rainforest'. *Biodiversity and Conservation*. **5**: 135–168.

Hagvar, S. 1998. The relevance of the Rio Convention on biodiversity to conserving the biodiversity of soils. *Appl. Soil Ecol.* **9**: 1-7.

Hattar, S. J. S., Alfred, J. R. B. and Dartong, V. T. 1992. Soil acarina and collembola in forest and cultivated land of Khasi Hills, Meghalaya. *Record of Zoological Survey of India*. **92**: 89-97.

Hawksworth, D. L., and Mound, L. A. 1991. Biodiversity databases: The crucial significance of collections. p. 17-29. In: *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture* (Hawksworth, D. L., ed). CAB International, Wallingford, U.K.

Hazra, A. K. 1978. Ecology of Collembola in a deciduous forest floor of Birbhum District, West Bengal in relation to soil moisture. *Oriental Insects*. **12**: 265-274.

Heneghan, L. and Bolger, T. 1998. Soil microarthropod contribution to forest ecosystem processes: the importance of observational scale. *Plant and Soil*. **205**(2): 113-124.

Heneghan, L., Coleman, D. C., Zou, X., Crossley Jr., D. A. and Haines, B. L. 1998. Soil microarthropod community structure and litter decomposition dynamics: A study of tropical and temperate sites. *Applied Soil Ecology*. **9**: 33-38.

Huhta, V. and Hanninen, S. M. 2001. Effects of temperature and moisture fluctuations on an experimental soil microarthropod community. *Pedobiologia*. **45**(3):279-286.

Huhta, V. and Niemi, R. 2003. Communities of soil mites (Acarina) in planted birch stands compared with natural forests in central Finland. *Can. J. For. Res./Rev. Can. Rech. For*. **33**(2): 171-180.

Irmler, U. 2000. Changes in the fauna and its contribution to mass loss and N release during leaf litter decomposition in two deciduous forests. *Pedobiologia*. **44**(2): 105-118.

Irmler, U. 2004. Long-term fluctuation of the soil fauna (Collembola and Oribatida) at groundwater-near sites in an alder wood. *Pedobiologia*. **48**(4): 349-363.

Jandl, R., Kopeszki, H. and Glatzel, G. 1997. Effect of a dense Allium ursinum (L.) ground cover on nutrient dynamics and mesofauna of a Fagus sylvatica (L.) woodland. *Plant and Soil*. **189**(2): 245-255.

Kaneko, N. and Salamanca, E. 1999. Mixed leaf litter effects on decomposition rates and soil microarthropod communities in an oak–pine stand in Japan. *Ecological Research*. **14**(2): 131-138.

Kay, F. R., Sobhy, H. M. and Whitford, W. G. 1998. Soil microarthropods as indicators of exposure to environmental stress in Chihuahuan Desert rangelands. *Biology and Fertility of Soils*. **28**(2): 121-128.

Khan, S. 2005. *Soil characteristics of Dachigam National park*. Unpub. Master's Thesis, The University of Kashmir. Personal communication.

Laakso, J., Salminen, J. and Setala, H. 1995. Effects of abiotic conditions and microarthropod predation on the structure and function of soil animal communities. *Acta. Zool. Fenn*., **196**:162-167.

Lawrey, J. D. 1987. Nutritional ecology of lichen/moss arthropods. p. 209–233. In: *Nutritional Ecology of Insects, Mites, Spiders and Related Invertebrates* (Slansky, Jr., F. and Rodriguez, J. G., eds). New York: John Wiley and Sons.

Lenoir, L., Bentsen , J. and Persson, T. 2003. Effects of conifer resin on soil fauna in potential wood-ant nest materials at different moisture levels. *Pedobiologia*. **47**(1): 19-25.

Mir, G. M. 1986. *Faunistic Composition and Bioecological Studies of Soil Microarthropods of Coniferous Forest Ranges of Kashmir Valley*. Unpub. Ph.D. Thesis. The University of Kashmir, Srinagar – 6, J&K.

Norton, R. A . 1990. Acarina: Oribatida. p.779-803. In: *Soil Biology Guide* (Dindal, D. L., ed). John Wiley & Sons, Toronto.

Noti, M. Y., Andre, H. M., Ducarme, X. and Lebrun, P. 2003. Diversity of soil oribatid mites (Acari: Oribatida) from High Katanga (Democratic Republic of Congo): a multiscale and multifactor approach. *Biodiversity and Conservation*. **12**: 767-785.

Petersen, H., Jucevica, E. and Gjelstrup, P. 2004. Long-term changes in Collembolan communities in grazed and non-grazed abandoned arable fields in Denmark. *Pedobiologia*. **48**(5-6): 59-573.

Reddy, J. R. and Reddy, M. V. 1996. Structure of microarthropod communities associated with four types of leaf litters. *Journal of Soil Biology & Ecology*. **16**: 151-154.

Reynolds, B. C., Crossley Jr., D. A. and Hunter, M. D. 2003. Response of soil invertebrates to forest canopy inputs along a productivity gradient. *Pedobiologia*. **47**(2): 127-139.

Rusek, J. 1998. Biodiversity of Collembola and their functional role in the ecosystem. *Biodiversity and Conservation*. **7**(9): 1207-1219.

Swift, M. J., Heal, O. W. and Anderson, J. M. 1979. *Decomposition in Terrestrial Ecosystems*. Blackwell Scientific, Oxford, U.K.

Tsiafouli, M. A., Kallimanis, A. S., Katana, E., Stamou, G. P. and Sgardelis, S. P. 2004. Responses of soil microarthropods to experimental short-term manipulations of soil moisture. *Applied Soil Ecology*. **29**: 252-257.

Usher, M. B., Davis, P., Harris, J. and Longstaff, B. 1979. A profusion of species? Approaches towards understanding the dynamics of the populations of microarthropods in

decomposers communities. p. 359-384. In: *Population Dynamics* (Anderson, R. M., Turner, B. D. and Taylor, L. R., eds). Oxford: Blackwell Scientific Publications.

Wall, D. H. and Moore, J. C. 1999. Interactions underground: Soil biodiversity, mutualism, and ecosystem processes. *BioSci*. **49**:109-117.

Wallwork, J. A. 1970. *Ecology of Soil Animals*. McGraw Hill, London, U.K.

Webb, N. R. 1994. The role of Steganacarus magnus (Acari: Cryptostigmata) in the decomposition of the cones of Scots pine, Pinus sylvestris. *Pedobiologia*. **35**: 351-359.

Woolley, T. A. 1990. *Acarology : Mites and Human Welfare*. New York: J. Wiley, 463p.