FUNCTIONAL DIVERSITY OF SOIL INHABITING NEMATODES IN NATURAL FORESTS OF ARUNACHAL PRADESH, INDIA

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Summary. Arunachal Pradesh is one of India's biodiversity hotspots. The present study was based on samples collected from Tirap district in Arunachal Pradesh. This district is located at latitude 26°-38'N and 27°-47'N, longitude 96°-16'E and 95°-40'E, altitude 1200-1300 masl. The terrain is marked by high hills, deep ravines and valleys through which streams and rivers flow. The entire district consists mainly of tropical and subtropical evergreen forests with rich and varied fauna. Twenty soil samples were collected at random from natural forest areas. A total of 85 genera of nematodes were recorded, with predators representing the highest number (32%), followed by bacterial feeders (20%), fungal feeders (22%), herbivores (15%) and omnivores (11%). In terms of individual abundance, the fungal feeders were the most dominant group (29%), followed by predators (25%), bacterial feeders (20%), herbivores (16%) and omnivores (10%). A minimum of eleven and a maximum of 26 genera per sample were recorded with most of the samples containing fifteen-twenty genera. In terms of individual abundance, 600-1040 specimens per 100 cm^3 of soil were recorded with most of the samples containing 600-800 individuals. There was high positive correlation between omnivores and bacterivores, and moderate positive correlation between omnivores and herbivores, and omnivores and predators. Some positive correlation also existed between omnivores and herbivores, and predators and bacterivores. Three-dimensional diagrams based on cp values show that genus-based diversity was higher among cp 3-5 groups than cp 1 and 2 groups. Dendrograms of cluster analysis of different indices indicated a close functional similarity in the samples of this region, except for a few samples where the enrichment index was zero or very low because bacterial feeders (Rhabditidae and Panagrolaimidae) with cp 1 were absent or few in number.

Key words: Abundance, biomass, cladogram, maturity index, Shannon-Weaver index, trophic groups, Tirap.

Soil nematodes offer great potential for use as indicators of biodiversity and ecological stability, and for assessing the impact of changing land use on soil conditions. In the last decade or so, an increasing number of papers on nematode community structure, in relation to environmental changes or disturbances, have shown that different nematodes having different life spans, different reproductive and survival capacities (occupying habitats that vary from pristine to extremely polluted), different positions in the food web, respond differently to environmental changes, and can be used as ecological bioindicators (Freckman, 1982; Samoiloff, 1987; Bongers, 1990) and bio-control agents (Jairajpuri and Bilgrami, 1990; Ahmad, 1990). The assemblage of plant and soil nematode species occurring in a natural or a managed ecosystem constitutes the nematode community. Functional groups of nematodes can be regarded as groups of species that have similar effects on ecosystem processes. The ecological classification of terrestrial nematodes has usually been based on their feeding biology (trophic function) and on their life strategies, as colonizers *versus* persisters (Bongers, 1990). Nematode ecologists generally recognize five major trophic groups among soil inhabiting nematode species based on the nature of their feeding apparatus (Yeates *et al.*, 1993; Yeates, 1998; Yeates and Bongers, 1999). Within the five trophic groups, strong relationships are found between herbivores and fungal feeders, between herbivores and predators, and between fungal feeders and predators (Gomes *et al.,* 2003). The degree of correlation between different trophic groups is calculated by using the Karl Pearson coefficient of correlation, which measures the degree of correlation between two or more variables and is based on the arithmetic mean and standard deviation.

To assess the importance of soil nematodes in the ecosystem, we need a thorough knowledge of nematode population structure in different habitats. The abundance of each species in the community can be transformed into ecological indices and parameters to measure changes in diversity and trophic structure in the community and further to assess soil disturbance levels and decomposition pathways (Gomes *et al.*, 2003). Ecological indices based on the proportional contribution of each nominal taxon, such as the Shannon-Weaver index (Shannon and Weaver, 1949) and the Simpson index, are used to assess diversity (Wasilewska, 1979; Yeates, 1984). Species richness is assessed by using Margalef's index (Margalef, 1958). Maturity index (MI) and plant parasitic index (PPI) provide focused tools for assessing the response of nematode assemblages to disturbances. The cp (coloniser-persister) values (Bongers, 1990) of species reflect the perceived positions on an r-k spectrum based on their re-

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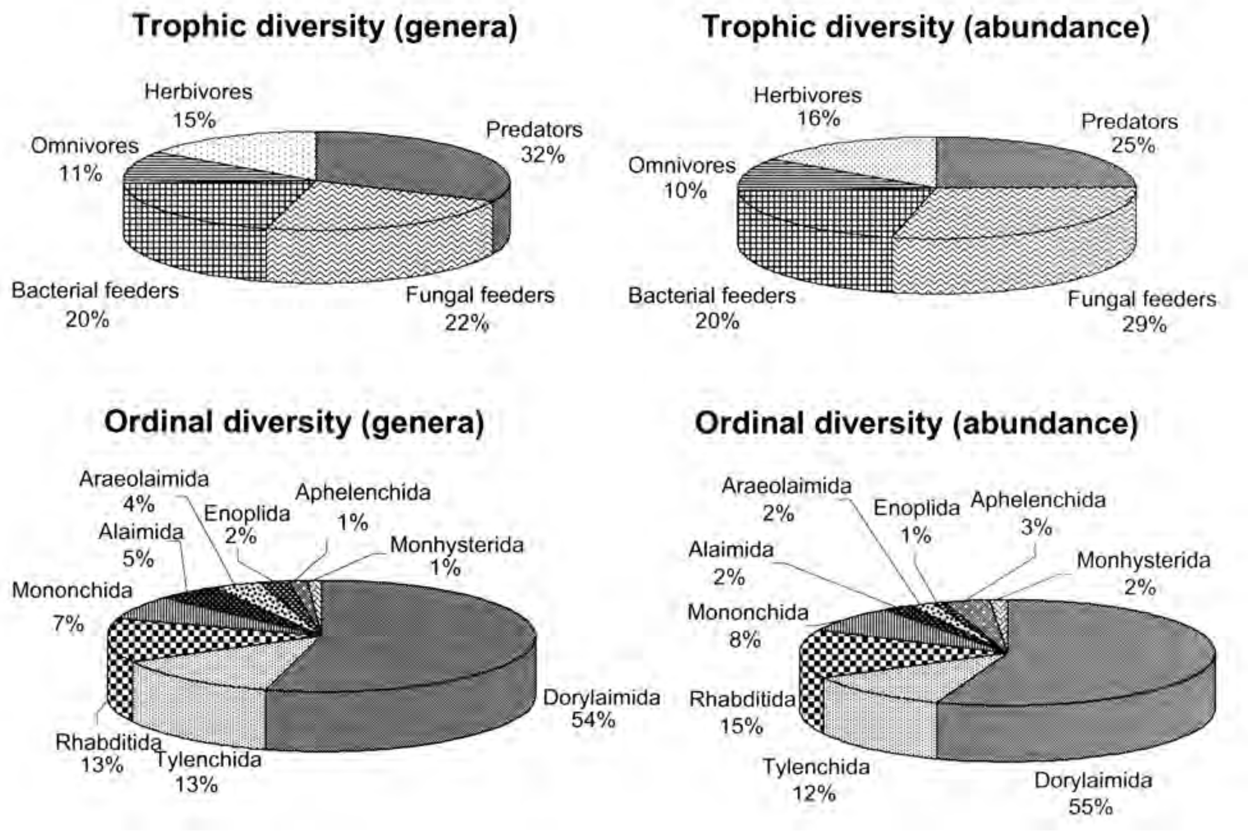

Fig. 1. Community structure of soil inhabiting nematodes in Tirap.

productive rate and correlated characteristics. The ratio between abundance of two functional groups, *i.e.* bacterivores and fungivores, gives an index of the relative contribution of the two main decomposition channels. It is expressed as the Nematode Channel Ratio (NCR). Various functional guilds of nematodes have been described to compute Enrichment index (EI) and Structure index (SI) (Ferris *et al.*, 2001). The enrichment index is based on the expected responsiveness of the opportunistic guilds to the food resource enrichment. Thus, EI describes whether a soil ecosystem is nutrient enriched (high EI) or depleted (low EI). The SI represents an aggregation of functional guilds with cp values ranging from 3 to 5. SI describes whether a soil ecosystem is structured/matured (high SI) or disturbed/degraded (low SI).

India is one of the twelve mega-biodiversity regions with 7.7% of the genetic resources of the world. The regions of India with the highest biodiversity are North-East (area 5.2%) and Western ghats (4.0%). Arunachal Pradesh is one of the biodiversity rich spots among the North Eastern States of India. The Natural forests of Tirap district of Arunachal Pradesh are rich in humus and organic constituents, harbouring a variety of soil invertebrates that includes numerous interesting nematode species. Since nematodes play a defined role as bio-indicators, a thorough study of the dominance and distribution of nematodes representing different trophic groups in diverse habitats of this sector would be very useful. Studies of measures of correlation and cluster analysis of nematode populations using different indices are very useful as nematodes are relatively sensitive to pollution-induced stress. In view of this the present

Table I. Characteristics of the site.

Characteristic	Specification
Soil type	Red loamy soil
Type of forest	Tropical wet evergreen forest and subtropical evergreen forest
Altitude	1200-1300 masl
Latitude	26° 38′ N and 27° 47′ N
Longitude	96° 16′ E and 95° 40′ E
Average annual rain fall	200-400 cm
Average annual temperature	20-22° C
Soil pH	4.5-5.2
Geological scale	Tertiary

study was planned. Nematodes were isolated using standard techniques; identification to genus and counting were done in the laboratory. Statistical analyses were made to analyze the frequency of distribution, dominance, density and biomass of different trophic and taxonomic groups and the relationships between the groups. Indices such as the Shannon-Weaver index, Simpson index, Margalef's index, Maturity index, plant parasitic index, nematode channel index, enrichment index and structural index were also calculated.

MATERIALS AND METHODS

Site description, soil sampling and processing. Tirap district derives its name from the river Tirap, which originates from this district. The entire area of Tirap is covered by high hills and deep gorges. The region is in a geographical setting bounded to the south by Myanmar, in the north by Assam state, in the west by the state of Nagaland and in the east by Changlang district of Arunachal Pradesh. The characteristics of the site are reported in Table I.

Twenty soil samples were collected at random from the root zones of pine (*Pinus sylvestris* L.), teak (*Tectona grandis* L.), bamboo (*Babusa tulda* L.), citrus (*Citrus aurantifola* (Christm *et* Panzer) Swingle), oak (*Quercus suber* L.), banana (*Musa paradiasca* L.), hollock tree (*Terminalia myriocarpa*, Van Heurck *et* Muell), and some unidentified trees and herbs and from litter and soil in natural forests. Five sub-samples were collected from a depth of about 10-15 cm from each site. These sub-samples were mixed to make a composite sample from which 100 cm^3 of soil was taken for further processing. Isolation of nematodes was by Baermann funnel technique.

Community analysis and diversity indices (Norton, 1978, Tomar *et al.*, 2006)

The following parameters were used:

Frequency (N): Frequency of nematode genus (*i.e.* the number of samples in which the genus was present).

Absolute frequency (AF%): (Frequency of the genus) × 100/total number of samples counted.

Density (MD): Number of nematode specimens of the genus counted in all samples/total number of the samples collected.

Relative density (RD%): Mean density of the genus × 100/sum of mean density of all nematode genera.

Mean biomass (MB) µg: (Biomass of one nematode individual of the genus) × (absolute density of the genus).

Relative biomass (RMB) µg: (Mean biomass of the genus) × (100)/sum of biomass of all genera).

The following indices were calculated:

Shannon-Weaver Index (H') = $-\Sigma$ Pi In Pi

Maturity Index (MI) = $\sum_{i=1}^{n} V(i)+(i)$

Plant Parasitic Index (PPI) = Σ PPi Xi / Σ Xi

Nematode Channel Ratio (NCR) = B/B + F

In these indices, Pi = proportion of individual of taxon *i* in the total population; PPi = cp values assigned to taxon *i* according to Bongers (1990), Xi = abundance of taxon *i* in the sample, B = abundance of bacterivore nematodes, F = abundance of fungivore nematodes.

Enrichment Index (EI) = (e/e+b) × 100
Structure Index (SI) = (s/s+b) × 100,
where e, b and s are sum products of assigned weights and number of individuals of all genera.

Cluster analysis dendrograms and other statistical calculations were done using the computer programme STATISTICA.

RESULTS

Nematode biodiversity

A total of 85 genera were recorded, with predators representing the highest number (32%), followed by fungal feeders (22%), bacterial feeders (20%), herbivores (15%) and omnivores (11%). In terms of individual abundance, fungal feeders were the most dominant group (29%), followed by predators (25%), bacterial feeders (20%), herbivores (16%) and omnivores (10%) (Fig. 1). In terms of taxonomic groups, among the 85 genera identified 54% belonged to Dorylaimida, followed by Rhabditida and Tylenchida (with 13% each), Mononchida (7%), Alaimida (5%), Araeolaimida (4%), Enoplida (2%), Aphelenchida and Monhysterida (1% each). In terms of abundance also, Dorylaimida were the dominant group (55%), followed by Rhabditida (15%), Tylenchida (12%), Mononchida (8%), Aphelenchida (3%), Alaimida, Araeolaimida and Monhysterida (2% each) and Enoplida (1%) (Fig. 1). A minimum of eleven and a maximum of 26 genera per sample were recorded, with most of the samples containing fifteen-twenty genera. In terms of individual abundance, 600-1040 specimens per 100 cm^3 of soil were recorded, with most of the samples containing 600-800 individuals. In the entire region, the genus *Axonchium* was the most dominant with the highest frequency of occurrence (85%), mean density (52.1 per 100 cm^3 of soil), relative density (7.73), and mean biomass (112.4 µg), while the genus *Paraoxydirus* was the least common with frequency of occurrence of 5% and mean density of 0.9 per 100 cm^3 of soil (Table II).

Frequency (Table II). Among predators, the genus *Makatinus* was the most prevalent (13/20) with absolute frequency (AF) of 65%, whereas the least frequent genera were *Labronemella*, *Mylodiscus*, *Enchodelus*, *Clarkus* and *Mulveyellus* with N = 1 and AF = 5 each. *Eudorylaimus* was the most frequent genus among the omnivores with a frequency of 8/20 and absolute frequency of 40%, while the genera *Indodorylaimus*, *Thonus* and *Epidorylaimus* (N = 1, AF = 5) were the least frequent.

Table II. Population structure of soil inhabiting nematodes in Tirap sector.

Genera	Cp[1] value	N	AF (%)	MD	RD (%)	MB	RMB (%)
Predators							
Laimydorus	4	4	20	5.0	0.74	4.80	0.56
Aporcelaimellus	5	8	40	18.0	2.67	42.8	5.02
Aporcelaimium	5	1	5	1.20	0.17	4.62	0.54
Makatinus	5	13	65	24.0	3.56	112.3	13.18
Labronema	4	6	30	8.0	1.18	21.52	2.52
Labronemella	4	1	5	1.20	0.17	7.42	0.87
Discolaimus	5	3	15	5.0	0.74	3.05	0.35
Discolaimoides	5	1	5	1.45	0.21	1.97	0.23
Mylodiscus	5	1	5	2.30	0.34	3.10	0.36
Coomansinema	4	2	10	3.0	0.44	6.06	0.71
Actinolaimus	5	4	20	6.0	0.89	6.78	0.79
Neoactinolaimus	5	1	5	1.45	0.21	7.10	0.83
Enchodelus	4	1	5	1.20	0.17	2.67	0.31
Nygolaimus	5	5	25	6.0	0.89	7.14	0.83
Nygellus	5	6	30	15.0	2.22	11.7	1.37
Nygolaimellus	5	1	5	2.0	0.29	0.62	0.07
Clavicaudoides	5	1	5	1.30	1.19	0.98	0.11
Aquatides	5	1	5	1.10	0.16	0.85	0.09
Mylonchulus	4	10	50	25.0	3.7	27.5	3.22
Clarkus	4	1	5	2.45	0.36	13.76	1.61
Coomansus	4	3	15	3.45	0.51	30.7	3.60
Mulveyellus	4	1	5	2.10	0.31	1.0	0.11
Iotonchus	4	10	50	21.0	3.11	60.48	7.10
Paramylonchulus	4	2	10	2.20	0.32	2.70	3.30
Afronygus	4	1	5	1.45	0.21	1.33	0.15
Tripyla	3	2	10	2.10	0.31	0.46	0.05
Ironus	4	3	15	5.10	0.75	2.29	0.26
Omnivores							
Mesodorylaimus	4	7	35	15.5	2.30	15.19	1.78
Prodorylaimus	4	5	25	7.10	1.05	11.78	1.38
Indodorylaimus	4	1	5	1.10	0.16	1.0	0.11
Eudorylaimus	4	8	40	23.25	3.45	56.7	6.65
Thonus	4	1	5	3.40	0.50	16.55	1.94
Epidorylaimus	4	1	5	1.30	0.19	0.22	0.02
Thornenema	5	7	35	9.10	1.35	10.28	1.20
Moshajia	4	2	10	5.15	0.76	5.51	0.64
Sicorinema	4	3	15	4.05	0.60	0.44	0.05
Bacteriovores							
Rhabditis	1	4	20	11.5	1.7	20.7	2.43
Mesorhabditis	1	2	10	4.45	0.66	0.84	0.09
Cephalobus	2	5	25	9.3	1.38	1.02	0.11
Eucephalobus	2	13	65	48.6	7.21	15.55	1.82
Chiloplacus	2	2	10	4.25	0.63	0.21	0.02
Zeldia	2	3	15	4.75	0.7	2.61	0.3
Plectus	2	3	15	3.95	0.58	1.46	0.17
Chiloplectus	2	2	10	3.6	0.53	2.66	0.31
Acrobeloides	2	4	20	8.1	1.2	0.97	0.11
Panagrolaimus	2	1	5	1.45	0.21	0.75	0.08
Panagrellus	2	1	5	3.1	0.46	0.18	0.02
Aphanolaimus	2	2	10	4.05	0.6	5.67	0.66
Pseudacrobeles	2	1	5	1.6	0.23	2.56	0.3

continued

Table II. Continuation.

Genera	Cp[1] value	N	AF (%)	MD	RD (%)	MB	RMB (%)
Turbatrix	2	2	10	3.75	0.55	5.62	0.65
Monhystrella	2	6	30	10.25	1.52	0.82	0.09
Alaimus	4	5	25	9.1	1.35	2.4	0.28
Etamphidelus	4	2	10	2.35	0.34	0.47	0.05
Amphidelus	4	2	10	2.20	0.32	0.41	0.04
Cristamphidelus	4	2	10	1.95	0.28	0.97	0.11
Fungivores							
Axonchium	5	17	85	52.1	7.73	112.4	13.19
Belondira	5	8	40	16.45	2.44	4.44	0.52
Oxydirus	5	1	5	1.30	0.19	0.89	0.10
Paraoxydirus	5	1	5	0.90	0.13	6.50	0.76
Dorylaimellus	5	9	45	19.1	2.83	17.19	2.01
Tylencholaimus	4	5	25	7.0	1.03	0.56	0.06
Tantunema	4	1	5	0.90	0.13	0.19	0.02
Leptonchus	4	3	15	3.75	0.55	3.30	0.38
Tyleptus	4	1	5	2.25	0.33	0.33	0.03
Promumtazium	4	1	5	1.60	0.23	0.57	0.06
Basirotyleptus	4	3	15	7.65	1.13	5.96	0.69
Tylencholaimellus	5	1	5	1.40	0.20	0.26	0.03
Dorylaimoides	3	12	6	34.05	5.05	34.05	3.99
Filenchus	2	5	25	10.5	1.55	0.94	0.11
Aglenchus	2	2	10	5.75	0.85	0.06	0.007
Discomyctus	4	6	30	10.25	1.52	0.27	0.03
Aphelenchus	2	10	50	20.0	2.96	0.23	0.02
Herbivores							
Acephalodorylaimus	4	7	35	15.13	2.27	1.68	0.19
Xiphinema	5	7	35	10.1	1.49	38.9	4.56
Trichodorus	4	2	10	2.05	0.03	0.28	0.03
Oriverutus	4	9	45	16.3	2.41	21.5	2.52
Hoplolaimus	3	4	20	11.2	1.66	16.35	1.19
Scutylenchus	3	1	5	2.0	0.29	0.60	0.07
Helicotylenchus	3	10	50	37.1	5.5	6.67	0.78
Basiria	3	1	5	1.25	0.18	0.21	0.02
Merlinius	3	1	5	1.05	0.15	0.37	0.04
Criconema	3	1	5	1.35	0.20	2.11	0.24
Hemicriconemoides	3	3	15	5.95	0.88	4.87	0.57
Hoplotylus	3	1	5	1.15	0.17	0.23	0.02
Pratylenchus	3	1	5	2.05	0.30	0.20	0.02

[1] Cp scale – Allocation of values on colonizer-persistor scale (Bongers, 1990).
N, frequency; AF, absolute frequency; MD, density; RD, relative density; MB, mean biomass; RMB, relative biomass.

Among bacterial feeding nematodes, the highest frequency was recorded for *Eucephalobus* (N = 13) with an absolute frequency of 65%. The genera *Panagrolaimus*, *Panagrellus*, and *Pseudacrobeles* (N = 1) were the least frequent with AF = 5. Among fungal feeders, *Axonchium* was the most prevalent (N = 17), with absolute frequency of 85%. The least frequent genera were *Tantunema*, *Paraoxydirus* and *Oxydirus* (N = 1 and AF = 5 each)**.** Among plant parasitic and suspected plant parasitic nematodes, *Helicotylenchus* was the most frequent genus (N = 10), with an absolute frequency of 50%. The genera *Scutylenchus*, *Basiria*, *Merlinius*, *Criconema*, *Hoplotylus* and *Pratylenchus* (N = 1), with an absolute frequency of 5% each, were the least frequent.

Mean density (Table II). *Mylonchulus* was the most dominant genus (MD = 25) among predators, with relative density of 3.7%. The least dominant genus was *Aquatides* (MD = 1.1). Among omnivores, *Eudorylaimus* was the most dominant genus (MD = 23.25) with a relative density of 3.45%. *Epidorylaimus* (MD = 1.3) with relative density of 0.19% and *Indodorylaimus* (MD = 1.1) with relative density of 0.16% were the least dominant genera. The genus *Eucephalobus* (MD = 48.6) was the most dominant genus among bacteriovores with relative density of 7.21%. The least dominant genera were *Pseudacrobeles* (MD = 1.6), RD = 0.23, and *Panagrolaimus* (MD = 1.75). *Axonchium* (MD = 52.1) constituted the most dominant genus in the fungivore group with relative density of 7.73%, whereas the least dominant genera were *Paraoxydirus* and *Tantunema* (MD = 0.9) with relative density of 0.13% each. *Helicotylenchus* was also the most dominant genus in the herbivore group, with a mean density of 37.1 per 100 cm^3 of soil and relative density of 5.5%. The genera *Basiria* (MD = 1.25, RD = 0.18), *Hoplotylus* (MD = 1.15), and *Merlinius* (MD = 1.05, RD = 0.15) were the least dominant.

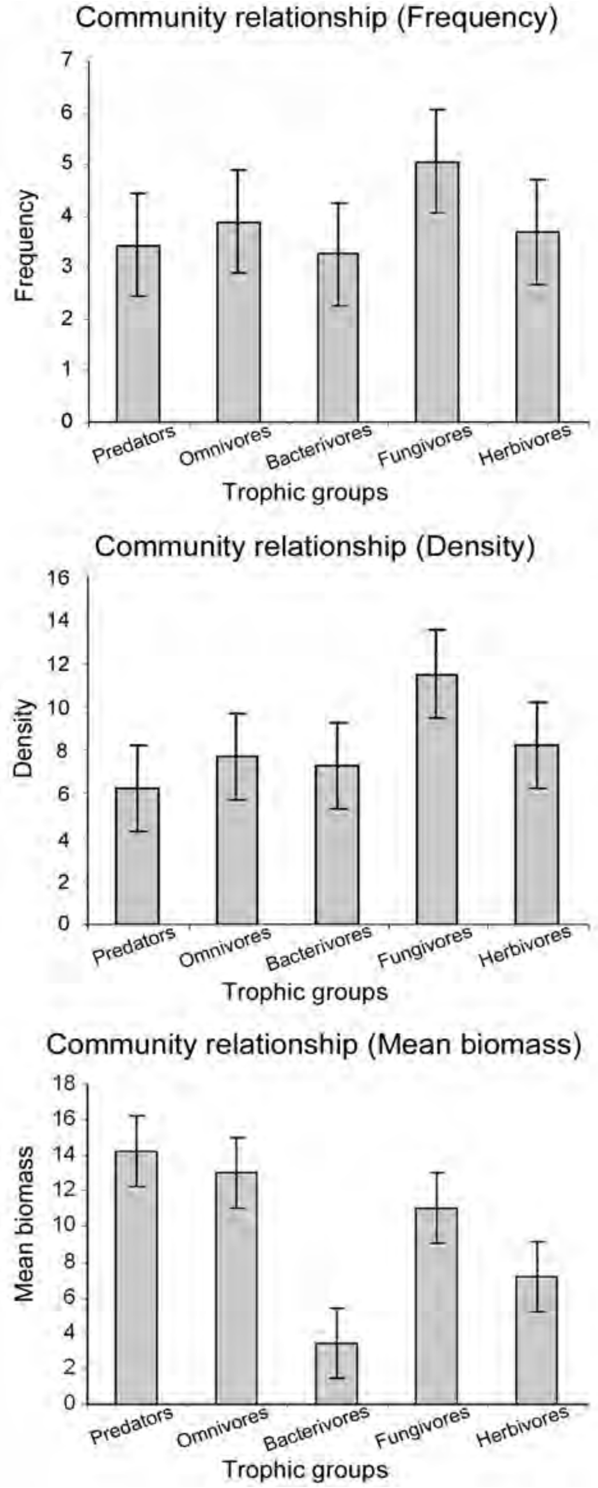

Fig. 2. Bar chart showing ratio between different trophic groups (Frequency, Density and Mean biomass).

Mean Biomass (Table II). *Makatinus,* being large-sized, constituted the highest biomass in the predatory group, with a mean value of 112.32 µg and relative mean biomass of 13.18%. The least biomass was recorded for *Tripyla* (0.46 µg), with relative mean biomass of 0.05%. The genus *Eudorylaimus* also is large-sized and, having a comparatively high density, had the highest mean biomass (56.7 µg) and relative mean biomass of 6.65% in the omnivore group, while the genera *Sicorinema* (0.44 µg, RMB = 0.05) and *Epidorylaimus* (0.22 µg, RMB = 0.02) had the least mean biomass. Although *Eucephalobus* was the most frequent and had a high density, *Rhabditis* (20.7 µg), with a relative mean biomass of 2.43%, had the highest mean biomass among the bacterivores. The genera *Chiloplacus* (0.21 µg, RMB = 0.02) and *Panagrellus* (0.18 µg, RMB = 0.02) had the least mean biomass. Among fungal feeding nematodes, *Axonchium*, due to its high density, constituted the highest mean biomass (112.4 µg) and had a relative mean biomass of 13.19%. The genera *Tantunema* (0.19 µg, RMB = 0.02) and *Aglenchus* (0.06 µg, RMB = 0.007) had the least mean biomass in this group. Although *Helicotylenchus* was the most dominant genus in the herbivore group, *Xiphinema*, being large-sized, had the highest mean biomass (38.9 µg) and a relative mean biomass of 4.56%. The genera *Basiria* and *Pratylenchus*, of small size, had the least mean biomass (0.21 µg and 0.02 µg) with a relative mean biomass of 0.02%.

Trophic relationships among soil-inhabiting nematodes (Table III; Figs 2-5)

Frequency. The fungal feeders were the most prevalent group in the entire nematode community with N = 5.05 [CV(coefficient of variation) = 93%], AF = 25.2 (CV = 94%), whereas bacterial feeders represented the least frequent group in this community with a frequency N = 3.26 (CV = 85%) and absolute frequency of 16.31 (CV = 85%). A high positive correlation was recorded between omnivores and herbivores (+0.89), and there was also some correlation between bacterivores and omnivores (+0.54), bacterivores and predators (+0.44), and herbivores and predators (+0.43). No correlation was recorded between fungivores and omnivores (-0.01), fungivores and bacterivores (-0.18) and the remaining trophic groups.

Density. Fungal feeders were the most dominant group in the entire nematode community with D = 11.46 (CV = 120%) and relative density of 1.69 (CV = 121%), whereas predators were the least dominant with D = 6.22 (CV = 119%) and relative density of 0.91 (CV

Table III. Community relationships between different trophic groups.

	Predators	CV[1] %	Omnivores	CV %	Herbivores	CV %	Bacterivores	CV %	Fungivores	CV %
N	3.44±3.35 (1-13)	97	3.88±2.89 (1-7)	74	3.69±3.37 (1-10)	91	3.26±2.76 (1-13)	85	5.05±4.72 (1-17)	93
AF%	17.22±16.77 (15-65)	97	19.4±14.45 (5-40)	74	18.4±16.8 (5-50)	91	16.31±13.8 (10-65)	85	25.2±23.61 (5-85)	94
MD	6.22±7.39 (1.12-25	119	7.7±7.3 (1.1-15.5)	95	8.21±10.32 (1.05-37.1)	126	7.27±10.4 (1.45-48.6)	143	11.46±13.82 (0.9-52.1)	120
RD%	0.91±1.09 (0.16-3.56)	120	1.15±1.08 (0.16-2.3)	94	1.21±1.53 (.15-5.50)	126	1.07±1.55 (0.21-7.21)	145	1.69±2.05 (0.03-7.73)	121
MB	14.28±24.31 (0.46-112)	170	13.06±17.5 (0.22-56.7)	134	7.22±11.68 (0.20-38.9)	162	3.46±5.47 (0.18-20.7)	158	11.06±27.51 (0.06-112.4)	248
RMB%	1.78±2.86 (0.08-13.18)	161	1.53±2.05 (0.05-6.65)	134	0.84±1.37 (0.02-4.56)	163	0.40±.64 (0.02-2.43)	160	1.29±3.23 (0.007-13.19)	250

[1]CV = coefficient of variation; N = frequency; AF = absolute frequency; MD = density; RD = relative density; MB = mean biomass; RMB = relative biomass.

= 120%). There was some positive correlation between omnivores and herbivores (+0.57), and predators and bacterivores (+0.45). No correlation was found between herbivores and bacterivores (+0.28), herbivores and predators (+0.20), fungivores and omnivores (+0.18), and other trophic groups.

Mean Biomass. The highest mean biomass in the entire nematode community was recorded for predators, 14.28 µg (CV = 170%) with relative mean biomass of 1.78 µg (CV = 161%), whereas bacterial feeders had the least mean biomass 3.43 µg (CV = 158%) and relative mean biomass of 0.40% (CV = 160%). High positive correlation existed between predators and omnivores (+0.77), and moderate positive correlation between bacterivores and fungivores (+0.73), and between omnivores and bacterivores (+0.63). There was also some positive correlation between omnivores and herbivores (+0.54), predators and herbivores (+0.57), and bacterivores and predators (+0.36). No correlation was recorded between the remaining trophic groups.

Abundance. A high positive correlation was found between omnivores and bacterivores (+0.80), with moderate positive correlation between omnivores and herbivores (+0.55), and omnivores and predators (+0.40); no correlation was found between predators and fungivores (-0.08), bacterivores and fungivores (-0.09), and fungivores and herbivores (0.06).

In Table IV, the values of the main diversity indices relative to nematode diversity and life strategies are given.

Relationships between different indices, such as MI, MI2-5, Structural index and Enrichment index of each sample, indicative of a highly stable ecosystem, are shown in Fig. 6.

Table IV. Summary of nematode diversity indices of Tirap sector in Arunachal Pradesh.

Index	Values
Generic richness	
Margalef diversity (d)	8.840
Shannon-Weaver index (H' gen)	3.865
Simpson diversity index (Ds) (random samples)	0.969
Inverse Simpson diversity index (random samples)	32.429
Pielou's evenness (J')	0.870
Simpson diversity evenness	0.981
Maximum diversity	0.988
Inverse Simpson diversity evenness	0.379
Maximum diversity	85.536
Simpson dominance.	0.969
Maturity index	3.37
Plant parasitic index	3.30
Nematode channel ratio	0.41

DISCUSSION

In recent years, much emphasis has been given to below-ground diversity and its relationship with above-ground diversity. In soil, nematodes, collembolans and mites are three groups of mesofauna considered as important biological indicators. Of the three groups, nematodes may be the most suitable for environmental diagnosis based on the community structure analysis because more information exists on their taxonomy and feeding roles (Gupta and Yeates, 1997) than for other mesofauna and they can be used in case studies for biomonitoring and ecological investigations. Routine analysis of the nematode fauna provides a rapid assessment of responses to management activity and environmental stress and thereby provides decision criteria for conservation and remediation. Understanding the role of nematodes in these processes is also a key to understanding the relationships between plant and soil nematode communities.

In the present study, 85 genera were recorded with predators representing the greatest number of genera, whilst fungal feeders dominated other groups in terms of individual abundance. Such abundance and variety of predators is quite uncommon in most ecosystems and is clearly related to the absence of man-induced disturbance and the rich food web of the site. Within taxonomic groups, Dorylaimida dominated in terms of number of genera as well as abundance. This is due to the

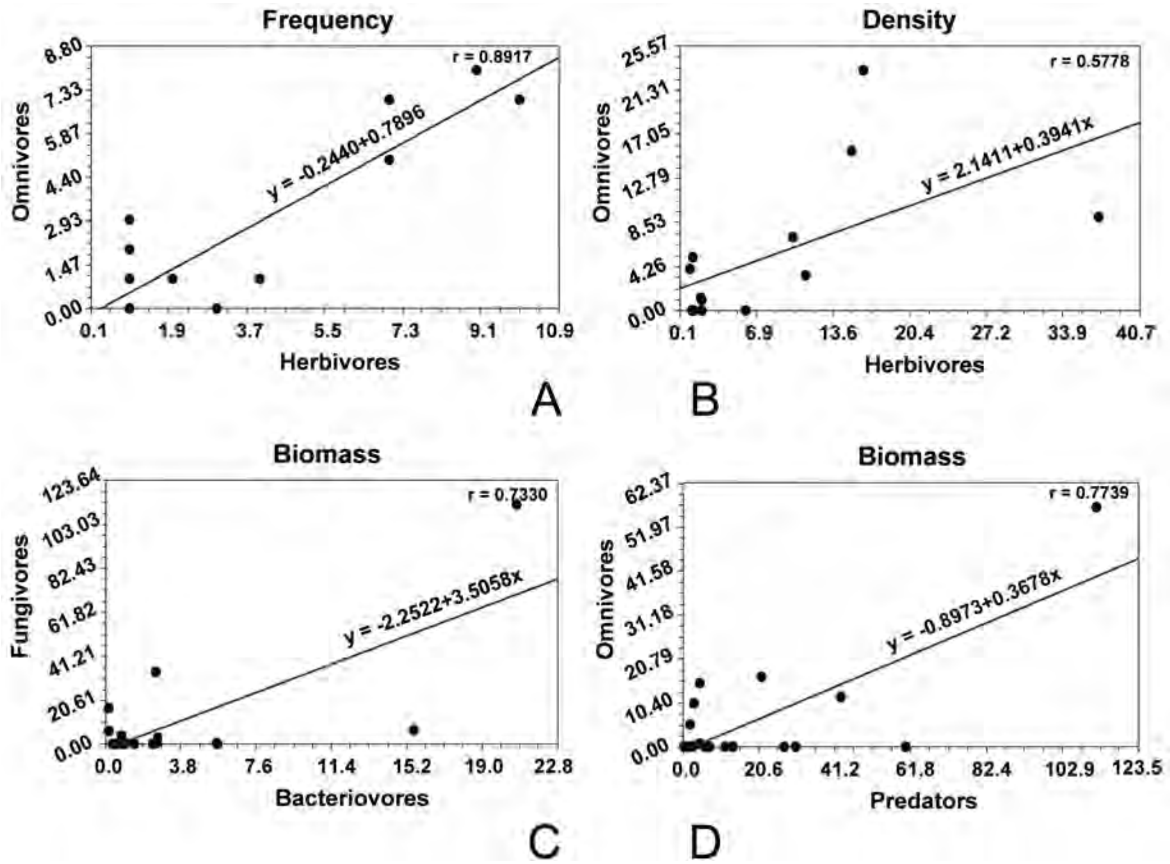

Fig. 3. Correlation between trophic groups.

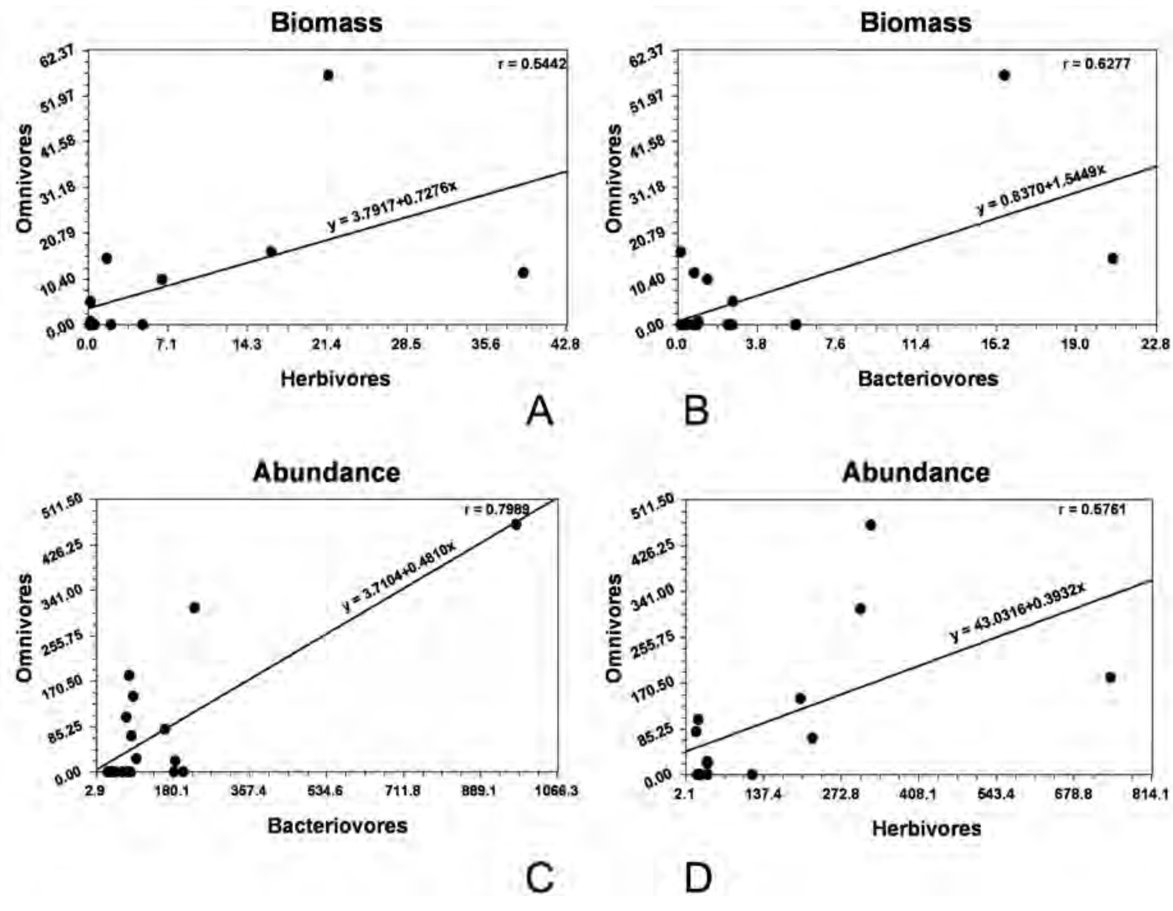

Fig. 4. Correlation between trophic groups.

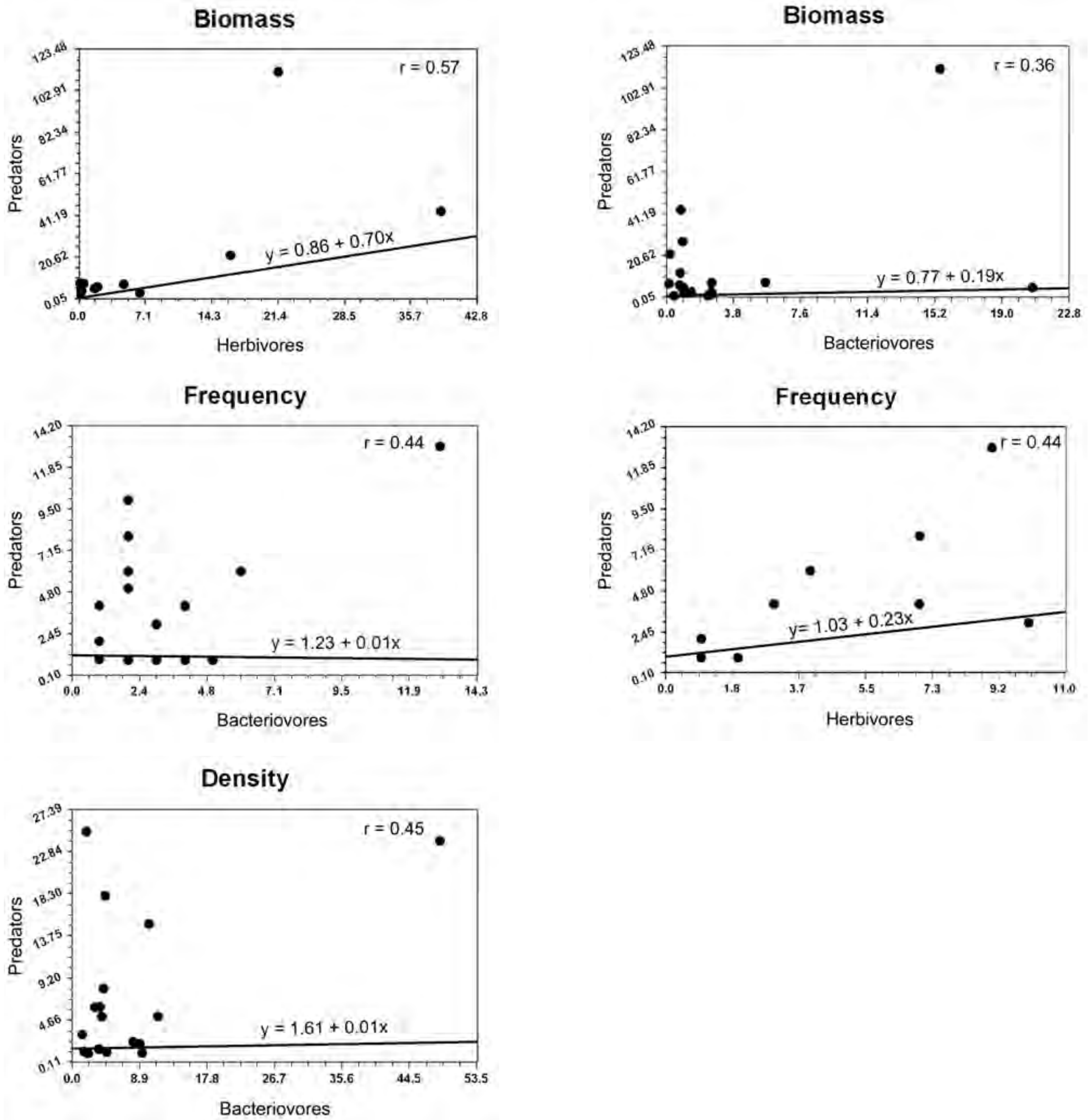

Fig. 5. Correlation between trophic groups.

high degree of stability of this region, which has been free of human intervention. This finding is in agreement with earlier reports that populations of dorylaimids in the nematode community are sensitive to disturbance (agricultural practices such as ploughing, fertilizers and pesticides) and are therefore used as indicators of environmental disturbances (Thomas, 1978; Sohlenius and Wasilewska, 1984). A high percentage (>25%) of dorylaimids indicates scarce human intervention in the field while a low percentage indicates the contrary (Gomes *et al.*, 2003). Although sensitivity of dorylaimids to disturbances is well documented, the reason for their sensitivity is not clear. One possibility is that they are sensitive to changes in the abundance or community structure of their food resources. Dorylaimids and mononchids may also be more directly sensitive than other nematode groups to disturbance-induced changes and to the physio-chemical conditions of the soil environment (Forge and Simard, 2001).

Among trophic groups, fungal feeders dominated in frequency and density, but predators constituted the highest mean biomass. A high to moderate positive correlation between bacterivores and omnivores, and between omnivores and herbivores, may be attributed to the rapid colonizing activity of bacterivores, which are enriched opportunists with short generation times, large gonad volume, and high rates of reproduction, mobility and metabolic activity. The omnivores, on the other hand, have low reproductive rates, long life cycles, low colonization ability and non-versatile feeding habits (Bongers, 1990; Bongers and Ferris, 1999). Being rapid colonizers, the bacterivores might be acting as a suitable food source for the omnivores, which are comparatively weak predators. The omnivore predators, with their protrusible odontostyles, may puncture the soft cuticle of the bacterivores comparatively easily and might have some kind of food preference. Hence, an increase in the population of bacterivores might favour the omnivore population. The positive correlation between omnivores and herbivores is in agreement with the statement of Yeates *et al.* (1993) and Yeates (1999) that omnivore nematodes utilize a combination of hyphae, bacteria, microfaunal prey, diatoms and algae, thus affecting the population of bacterial and fungal feeding nematodes. Therefore, an increase in the omnivore population will adversely affect the populations of other groups (although they may again colonize rapidly) other than herbivores, which depend on plant roots for their nutrition rather than soil micro-organisms. The rapid colonizers (bacterivores) are also indirectly responsible for increases in populations of herbivores. This finding is in agreement with the suggestion of Háněl (2003) that omnivore nematodes with versatile feeding habits probably intervene in various parts of the food web and compensate for the absence of species that are more dependent on undisturbed habitats. This free space might also be utilized by herbivores, whose populations would also then increase.

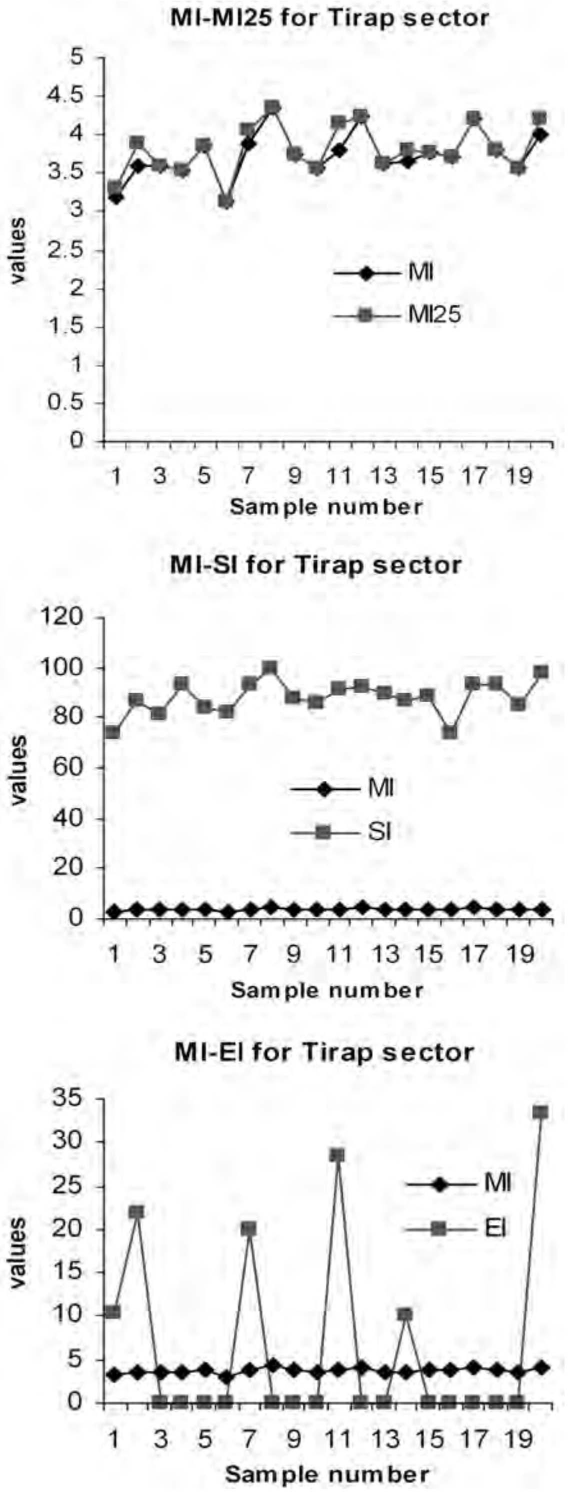

Fig. 6. Relationships between indices MI-MI25; MI-SI and MI- EI in 20 samples.

The various diversity indices, such as the Shannon-Weaver and Simpson diversity indices, showed that this site has a high nematode diversity. These results fully agree with Odum's prediction for forest as the mature stage of an ecosystem that shows high H' values (Odum, 1969). Different authors reported different values of H' in different habitats including forest areas. Háněl (1995) recorded the following successional variation of H': in the field 2.66 (1986), 2.83 (1987); in fallow 2.49 (1986), 3.16 (1987) and in forest 2.80 (1986), 2.48 (1987). The number of species was lower in the initial succession stages (field, fallow) than in the older ones (meadow, forest). The greatest specific and generic diversity (H') was found in meadow (Háněl, 1995). Háněl (1996) also found a decrease in the value of the Shannon-Weaver index with the age of the forest, whereas the maturity index was stable. Háněl (2003) recorded H' species and H' genus of 2.32-3.07 and 2.02-2.96 for soil nematodes in Combisol agro-ecosystems. Pattison *et al.* (2004) recorded H' values of nematode diversity for banana crop (1.35), pasture (1.97) and forest (2.07). This is in agreement with Yeates' statement (Yeates, 1996) that higher H' values are related to a relative abundance of Dorylaimida in forest soil. MI values for soil subjected to varying levels of disturbance range from >2.0 in nutrient enriched disturbed systems to ±4.0 in undisturbed, pristine environments (Bongers and Ferris, 1999). Similar changes were also observed in the values of maturity index in field (1.95, 2.35), fallow (2.61, 2.37), meadow (2.23, 3.12) and in forest (2.68, 2.22) (Háněl, 1996). The MI value of 3.37 in the present study suggests a highly stable ecosystem. The value of Nematode Channel Ratio (NCR) in this sector (0.41) showed that bacterial feeders were relatively sparser than fungal feeders. This NCR value was much lower than the 0.93 found by Yeates (1996) and 0.6 found by De Goede *et al.* (1993) for forest soil. A higher NCR value may reflect the abundance of mycorrhizal fungi (De Goede *et al.*, 1993) whereas the lower NCR value in

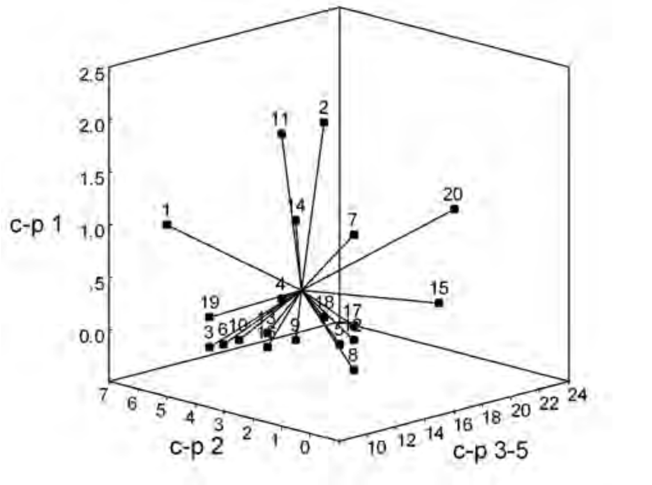

Fig. 7. Three-dimensional diagram showing number of genera representing different cp values in 20 samples.

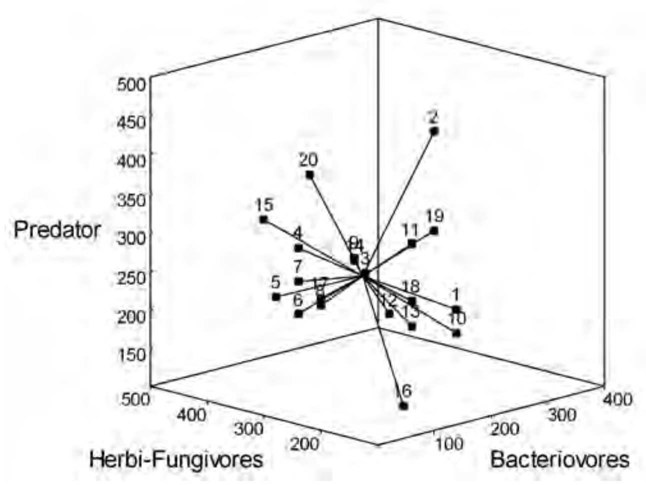

Fig. 8. Three-dimensional diagram showing abundance representing different trophic groups in 20 samples.

this region may be attributed to the lower pH (pH 4.5-5.2) of the soil. This finding is an agreement with observations by Alexander (1977) that the ratio of fungi to bacteria rises at lower pH, owing to the greater tolerance of acidity of the former and through reduced competition with other micro-organisms. A fungal dominated decomposition pathway and fungal feeding nematodes as predominant secondary decomposers are expected in forest systems, where cellulose- and lignin-rich litter material is the main source of nutrient input to the soil food web (Hohberg, 2003).

The three-dimensional diagrams based on cp values (Fig. 7) show that generic diversity was higher among the cp 3-5 groups than in the cp 1 and 2 groups, indicating undisturbed, stable pristine environmental conditions. Species in cp 3-5 are mainly represented by dorylaims, which are persisters, characterized by sensitivity to site disturbances, and are considered K-strategists (Bongers, 1999). A three-dimensional diagram of trophic groups (Fig. 8) showed that predators + omnivores and fungivores + herbivores dominated individual abundance more than bacterial feeders (colonizers), indicating stability in the ecosystem. Fungivores and herbivores are placed here in one group as some genera in these two groups have been classified alternately as herbivore or fungivore. The genera *Filenchus* and *Tylenchus* are considered as herbivore/plant associated nematodes (Yeates *et al.*, 1993; Yeates, 1998), while Sohlenius and Bostrom (1999), Okada *et al.* (2007) and many other nematologists consider them as fungal feeders + facultative root feeders. We also agree with the latter opinion that this group (*i.e.* most of the members of Ty-

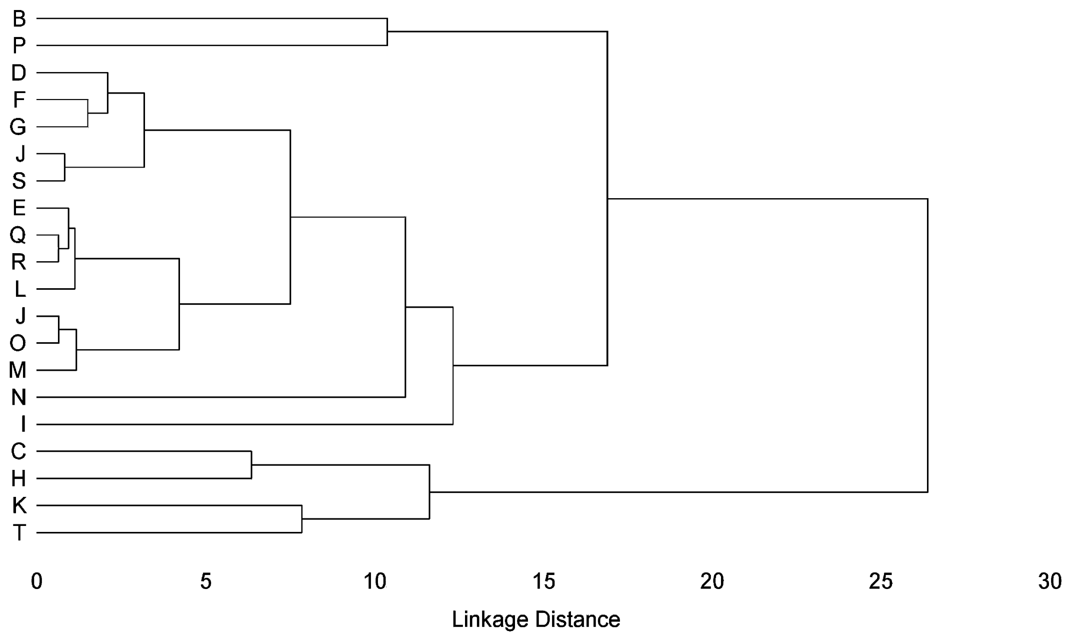

Fig. 9. Dendrogram of the cluster analysis of different indices in 20 samples (UPGMA, Euclidean distance) (each letter represents the sample number).

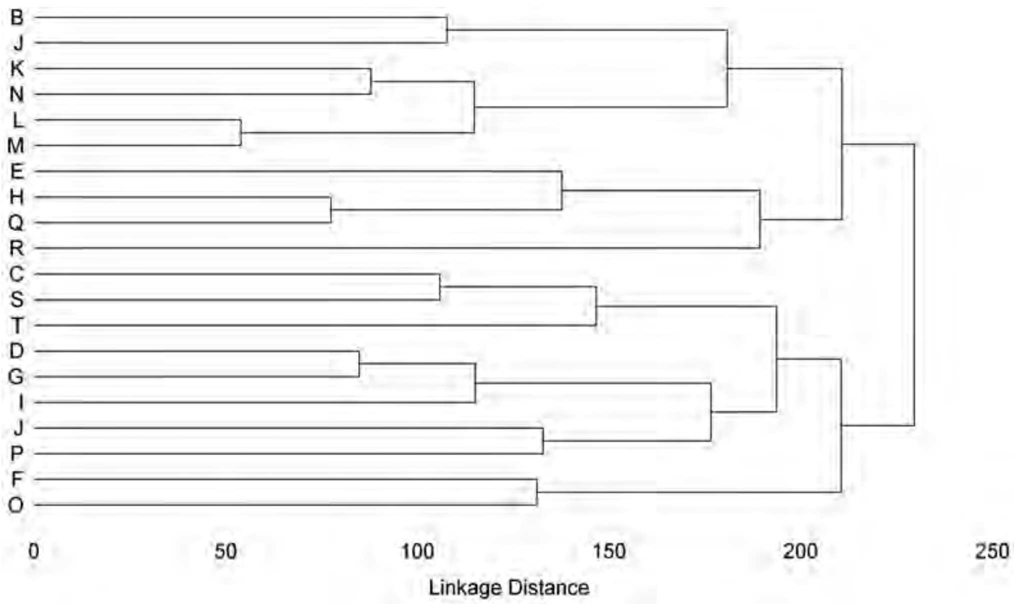

Fig. 10. Dendrogram of the cluster analysis of trophic groups in each of 20 samples (UPGMA, Euclidean distance) (each letter represents the sample number).

lenchidae) should be considered as fungal feeders + facultative root feeders.

The dendrogram of cluster analysis of different indices, such as MI, MI2-5, Structural index (SI) and Enrichment index (EI), of each sample (Fig. 9) showed that there is a close functional similarity in the samples of this region, except for sample nos 3, 8, 9, 11, 14 and 20, where enrichment index was zero or very low as bacterial feeders with cp 1 (Rhabditidae and Panagrolaimidae) were either absent or few in number in these sites. The dendrogram of cluster analysis of nematode abundance under different trophic groups (Fig. 10) also showed that there is a close relationship in each trophic group except in sample number 18, where the number of predators was very low compared with corresponding samples.

Mean abundance and percent share of nematodes in this sector (Table V) showed that no eudominant genus was found, with *Axonchium*, *Eucephalobus*, *Helicotylenchus* and *Dorylaimoides* as dominant genera. The higher number of belondirid nematodes showed the stability of the forest. The presence of strong predators, such as *Iotonchus*, *Actinolaimus* and *Ironus*, indicates that predatory groups have major roles in undisturbed forest ecosystems, and the higher number of rhabditids revealed the formation of abundant litter (higher bacterial production) in the forest.

Table V. Mean abundance and per cent share of nematode genera in Tirap sector of Arunachal Pradesh.

	% share	Genera
Eudominants	>10	Nil
Dominants	5.1-10	*Axonchium, Dorylaimoides, Eucephalobus, Helicotylenchus*
Subdominants	1.1-5	*Mesodorylaimus, Prodorylaimus, Thornenema, Aporcelaimellus, Makatinus, Eudorylaimus, Labronema, Acephalodorylaimus, Oriverutus, Xiphinema, Belondira, Dorylaimellus, Discomyctus, Basirotyleptus, Nygellus, Mylonchulus, Alaimus, Rhabditis, Cephalobus, Acrobeloides, Monhystrella, Filenchus, Hoplolaimus, Aphelenchus*
Recedents	≤1	*Laimydorus, Aporcelaimium, Labronemella, Discolaimus, Discolaimoides, Mylodiscus, Coomansinema, Actinolaimus, Neoactinolaimus, Enchodelus, Nygolaimus, Nygolaimellus, Clavicaudoides, Aquatides, Clarkus, Coomansus, Mulveyellus, Iotonchus, Paramylonchulus, Afronygus, Tripyla, Ironus, Indodorylaimus, Thonus, Epidorylaimus, Moshajia, Sicorinema, Mesorhabditis, Chiloplacus, Zeldia, Plectus, Chiloplectus, Paranygolaimus, Panagrellus, Aphanolaimus, Pseudoacrobeles, Turbatrix, Etamphidelus, Amphidelus, Cristamphidelus, Oxydirus, Paraoxydirus, Tylencholaimus, Tantunema, Leptonchus, Tyleptus, Promumtazium, Tylencholaimellus, Aglenchus, Scutylenchus, Basiria, Merlinius, Criconema, Hemicriconemoides, Hoplotylus, Pratylenchus.*

ACKNOWLEDGEMENT

The authors are thankful to the Department of Science and Technology (DST), Government of India for providing financial assistance.

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Accepted for publication on 30 July 2007.