EVALUATING THE INDICATIVE ROLE OF SOIL NEMATODE ASSEMBLAGES AND FOOD WEB INDICES IN TWO WETLANDS

Q. Tahseen*[1], A. Liang[2] and A. Hussain[1]

[1] *Nematode Research Laboratory, Department of Zoology, Aligarh Muslim University, Aligarh-202002, India*
[2] *Key Laboratory of Zoological Systematic and Evolution, Institute of Zoology, Chinese Academy of Sciences, Beijing, China*

Summary. Nematode assemblages and the food web indices were studied in a Ramsar wetland, Keoladeo National Park (KNP), India, and Yuan Ming Yuan Park (YMP), China also referred to as an imperial garden. The diversity indices (Shannon diversity index, Simpson's index of dominance, Margalef and Pielou J indices) indicated high diversity in the two habitats. A total of 82 and 79 nematode genera were identified in KNP and YMP, respectively. However, the composition of nematode assemblages at different sampling stations fluctuated occasionally. The Maturity Index (MI) generally indicated stability of the ecosystems, with the exception of some sampling sites at KNP that were found to be disturbed. The indicator values of Structure Index (SI) and Enrichment Index (EI) revealed stable, structured and nutrient-rich substrata at YMP and stable, structured, occasionally nutrient-stressed substrata at KNP.

Key words: Community structure, diversity indices, food web indices, functional guilds, nematodes.

Soil nematodes are numerous, relatively immobile organisms that contribute to soil biological processes, including decomposition of organic matter and C:N mineralization (Maggenti, 1981; Bongers, 1990; Wardle *et al.*, 1995). They interact closely with other organisms of the soil food web (Andrássy, 1984; Freckman, 1988a) and vary in reproductive potential from explosive opportunists to conservative survivalists. The nematodes recovered from soil can be affected by a number of factors including season (Barker *et al.*, 1969; Cooke *et* Draycott, 1971) and substrate type (Ayala *et al.*, 1963). Though their sensitivity to pollutants/disturbances varies yet some species are virtually the last animals to die in perturbed habitats (Samoiloff, 1987; Freckman, 1988b).

The study of nematode faunal composition thus provides information on succession, changes in decomposition pathways in the soil food web, nutrient status, sustainability and perturbations in the environment (Bongers *et* Ferris, 1999; Hoess *et* Traunspurger, 2002; Neher *et al.*, 2005). The community of soil nematodes generally responds in a characteristic way to autotrophic input from plants or subsidiary input from other sources leading to organic enrichment. The taxa of monophyletic families are generally adapted similarly to specific environmental conditions and food sources through anatomical and physiological commonalities and hence they are similar in their responses to disturbance. As nematodes represent multiple trophic groups (Yeates *et al.*, 1993), their community structure is analysed with respect to *c-p* (colonizer-persister) values reflecting their r-K spectrum or mode of invasion and establishment in the environment. The integration of nematode feeding groups (Yeates *et al.*, 1993) and the cp-scaling into functional guilds are the parameters used to assess the basal, enriched or structured status of food webs (Bongers *et* Bongers, 1998; Ferris *et al.*, 2001). The Shannon diversity index (Shannon *et* Weaver, 1949) and Simpson index, calculated on the basis of proportional representation of individual taxa, indicate diversity while Margalef's index (Margalef, 1958) depicts species richness in the ecosystem. These indices, however, give an appraisal of heterogeneity of organisms in a system but fail to give any information on the functional status of organisms or systems. The popular indices used to interpret the response of nematode assemblages to disturbances are the maturity index and plant parasitic index (Bongers, 1990; Bongers *et* Bongers, 1998). The quality of environment with respect to resource enrichment, as manifested by response of the opportunistic functional guilds, can be determined by Enrichment Index (EI) while Structure Index (SI) (Ferris *et al.*, 2001) indicates its structured or matured status. The relative contribution of fungivores and bacteriovores in the environment or the dominance of the fungal/bacterial decomposition pathway can be estimated by Nematode Channel Ratio (NCR) (Twinn, 1974). Thus the use of biological systems, especially nematodes, in the assessment of environment quality seems to be more explicable and cost-effective compared to the traditional limnological or chemical methods.

The present article analyses the nematode assemblages and their spatial functional characteristics for a comparative assessment of the substrate conditions in two geographically diverse habitats *viz.*, Keoladeo National Park (KNP), India and Yuan Ming Yuan Park (YMP), China.

* Corresponding author: qtahseen@yahoo.com; Phone +91 571 2700921-23/3440

MATERIALS AND METHODS

Description of sites

Keoladeo National Park (KNP), a Ramsar wetland as well as world heritage site, is a home to rich biological diversity. Located 2 km south-east of Bharatpur, Rajasthan, India, and situated close to Thar Desert, the wetland has a variety of sub-habitats including trees, shrubs, mounds, dykes and open water with or without submerged or emergent plants (Table I). It receives water twice a year from inundations of the Gambhira and Banganga rivers by means of an artificial dam called Ajan Bund. Although the wetland is supplied with water periodically by this means, still there has been a water crisis over the last five years. The park is an attraction for bird watchers and tourists.

Yuan Ming Yuan Park (YMP), situated on the northern suburbs of Beijing, China, is the largest and most luxurious imperial garden of the Qing dynasty, with a host of scenic sites representing different Chinese gardening styles. The habitat is well maintained with hills, ponds, a lake, ancient trees and diverse types of ornamentals (Table I).

Soil sampling and nematode extraction

Soil as well as sediment (10-15 cm deep) samples were randomly collected from KNP in 2005-06 and from YMP in 2008-09. Each sample represented a thoroughly mixed composite sample of three replicate subsamples. In each case, the volume of the processed soil/mud sample was 100 cm^3. Water samples taken from the top layers of flowing waters as well as periphytons were passed through 325 mesh sieves (pore size = 45 µm) held at a 45° angle. The samples were processed by sieving, decantation and modified Baermann's funnel technique. The residue in the coarse sieve was later examined for nematodes that failed to crawl into the water of the Baermann's funnel.

Nematode identification, counting and data analysis

The extracted nematodes were tentatively identified to genus rank and were allocated to feeding groups and *c-p* values according to Yeates *et al.* (1993) before making the counts. Fifty samples collected from distinct sampling sites were selected for each habitat for estimation of the various indices. Besides the basic statistical parameters *viz.*, frequency, relative frequency, density, relative density, mean biomass (Andrássy, 1956) and relative biomass (Norton, 1978), the various diversity and food web indices were calculated, including Maturity index

$$(MI) = \sum_{i=1}^{n} v(i) \times f(i)$$

where, v(i) = *c-p* value of taxon i and $f(i)$ = frequency of taxon i in a sample; Simpson Diversity Index

$$(\lambda) = \sum p_i^2;$$

Shannon diversity index

$$(H') = -\sum p_i \ln p_i$$

where p_i is the proportion of taxon i in the total sample, pp_i is the *c-p* value assigned to taxon i; Pielou J'

$$J' = H'/ \ln S$$

where H' is the Shannon index as defined above, and S is the number of species observed; Margalef's index

$$(SR) = (S\text{-}1)/\ln N,$$

where N is the number of individuals; Nematode Channel Ratio

$$(NCR) = B/B{+}F$$

where, B and F are the proportions of bacterial and fungal feeders; Enrichment Index

$$(EI) = \{e/e{+}b\} \times 100$$

and Structure Index

$$(SI) = \{s/s{+}b\} \times 100$$

where e, b and s are sum products of assigned weights and abundance of individuals in the corresponding *c-p* classes.

RESULTS

A total of 82 and 79 genera were identified in KNP and YMP respectively. However, the composition of ne-

Table I. Characteristics of Keoladeo National Park (KNP) and Yuan Ming Yuan Park (YMP).

Characteristic	KNP	YMP
Type	Wetland with mosaic of grassland, woodland and swamp	Garden with ornamentals, shrubs and trees and water bodies
Total area	29 sq km	3.50 sq km
Altitude	370-390 masl	44.4 masl
Latitude	27° 10' N	40° 25' N
Longitude	77° 31' E	116° 26' E
Climate	Arid to semi-humid	Semi-arid to semi-humid
Annual rainfall	400-550 mm	630-670 mm
Mininmum temperature	0 °C – (-2) °C	(-4) °C – (-8) °C
Maximum temperature	48 °C – 55 °C	28 °C – 32 °C
Soil type	Alluvial with intermittent sandy patches	Brown soil with a mixture of clay and loam
Soil pH	6.4 -7.5	6.5-7.0

matode assemblages at different sampling stations of the two habitats fluctuated occasionally. Even the diversity profiles varied with the sediment depths between sampling stations. The frequency as well as duration of sampling was insufficient to observe seasonal changes or to study the reproductive patterns of individual species. Soil temperatures reached lethal levels at the surface (above 42 °C in KNP in summer and below -7 °C in YMP in winter) but such temperatures occurred only in the top few cm and, with increasing depth, the temperatures were relatively moderate for nematode survival.

Abundance

A minimum of two genera were recorded in a sample at KNP, while the maximum number reached 20 at YMP, with mean value = 11 ± 6.27 genera per sample. The total numbers of nematodes ranged from 150 to 3285 with the mean value = 1530 ± 903.09 per 100 cm^3 soil. The count was considerably lower in samples taken from open water zones of each of the habitats.

Nematode trophic Structure

The trophic structure of the two habitats constituted the nematode categories of bacterivores, carnivores (predators), herbivores, omnivores and fungivores. Table II lists the various nematode genera found from the habitats according to their respective coloniser- persister (*c-p*) scores.

Generic diversity

Of the five functional guilds, cp-2 showed the maximum generic diversity (28%) in KNP, while generic diversity was greatest in cp-4 (26%) and cp-1 (28%) in YMP (Fig. 1A, B). The enrichment and basal indicators cp 1-2 represented more than half (52%) of the eighty-two genera found in KNP, while their share was 37% in YMP.

Frequency/Prevalence

The most frequent genera of the respective classes cp1-5 of KNP were *Mesorhabditis*, *Cephalobus*, *Helicotylenchus*, *Dorylaimus* and *Xiphinema* while in YMP the prevalent genera were *Aphelenchus*, *Geomonhystera*, *Hoplolaimus*, *Eudorylaimus* and *Axonchium* (Table II).

Density

The functional guild showing the greatest nematode density was cp-2 (35%) in KNP and cp-4 (47%) in YMP. However, the percentage composition of the enrichment and basal guilds together was 53% and 25%, respectively, in KNP and YMP (Fig. 1A', B'). Among the genera, *Cephalobus* was the most abundant in KNP while *Hoplolaimus* showed the greatest densities in YMP (Table II).

Relationship between frequency, density and biomass

The cp-1 individuals in KNP represented largely those with greater biomass but low density and frequency in the samples. In YMP, cp-1 individuals showed moderate prevalence and abundance as well as biomass (Fig. $2A_1$, B_1).

The individuals in cp-2 guild in KNP showed moderate to high biomass but were less to moderately frequent and abundant while cp-2 individuals in YMP had a moderate biomass and density but high frequency (Fig. $2A_2$, B_2).

The cp-3 guild showed trends more or less similar to the cp-2 guild in KNP, whereas in YMP the cp-3 nematodes with a greater biomass were relatively less fre-

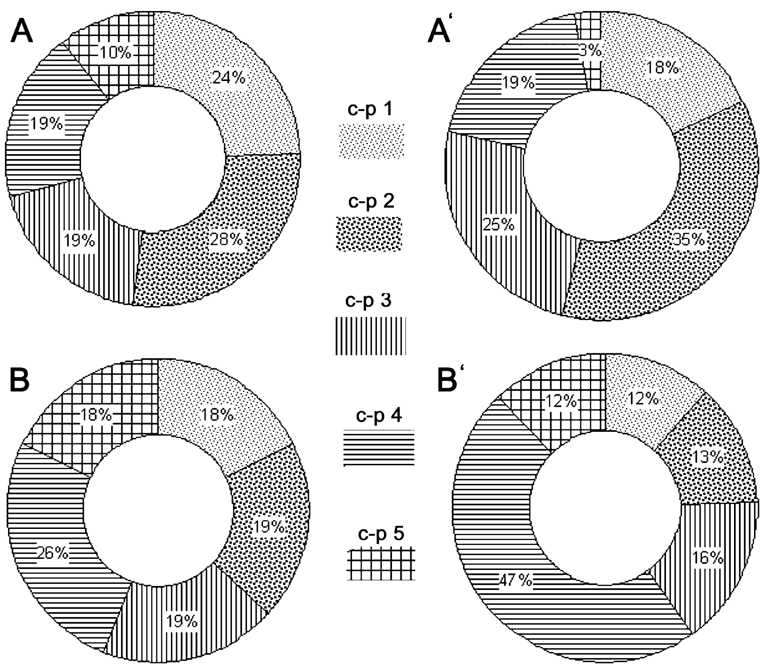

Fig. 1. A-B: Generic diversity; A'-B': Density of nematodes in KNP and YMP, respectively.

Table II. Nematode genera found in Keoladeo National Park and Yuan Ming Yuan Park along with their corresponding *c-p* scores, prevalence and abundance.

c-p value	Nematode Genus	Relative occurrence		Relative abundance	
		KNP	YMP	KNP	YMP
c-p 1	*Butlerius* (Ba)	0.77		0.25	
	Caenorhabditis (Ba)	0.96		0.28	
	Cruznema (Ba)	0.19	0.91	0.21	0.27
	Curviditis (Ba)	0.58		0.35	
	Cuticularia (Ba)	0.77		0.64	
	Diplogastritus (Ba)	0.96	0.18	0.17	0.22
	Diplogastrellus (Ba)	0.58	0.55	0.67	0.27
	Diploscapter (Ba)	1.54	1.48	0.42	0.55
	Distolabrellus (Ba)	0.77	0.73	0.61	0.80
	Eumonhystera (Ba)	1.16		0.39	
	Geomonhystera (Ba)	0.77	2.93	0.40	3.03
	Mesorhabditis (Ba)	7.71	2.75	8.30	2.86
	Metadiplogaster	0.96	0.55	0.66	0.86
	Monhystera	1.54	1.46	0.39	2.75
	Monhystrella	0.19		0.11	
	Mononchoides	0.58		0.21	
	Oscheius		0.73		0.33
	Panagrellus	2.70	2.56	1.67	2.20
	Panagrolaimus	1.35	1.28	1.49	1.03
	Pelodera	0.19	0.55	0.28	0.37
	Protorhabditis	1.16		0.77	
	Rhabditis	0.77	0.73	0.28	0.37
c-p 2	*Acrobeles*	1.73	1.65	3.69	1.23
	Acrobeloides	0.77	4.59	0.91	2.80
	Cephalobus	7.51	1.28	9.48	1.19
	Cervidellus	1.54	1.47	1.14	0.48
	Chiloplacus	5.20	2.75	7.32	1.43
	Eucephalobus	1.73	1.83	3.07	1.88
	Halicephalobus	0.19		0.24	
	Heterocephalobus	0.77	0.73	0.89	0.29
	Hoffmanneria	0.19		0.13	
	Plectus	1.16	1.83	0.29	1.31
	Ypsylonellus	0.58		0.33	
	Zeldia	0.58	0.55	0.42	0.55
	Aphelenchoides	1.35	1.28	0.68	0.90
	Aphelenchus	1.73	7.34	0.50	2.98
	Ditylenchus	0.19	0.37	0.10	0.13
	Seinura	0.77		0.25	
	Tylenchus	0.77	0.73	0.35	0.46
	Neotylocephalus	0.19		0.18	
	Aglenchus	0.77		0.45	
	Filenchus	0.58		0.18	
	Wilsonema		0.92		0.64
c-p 3	*Chronogaster*	1.93	3.12	1.21	2.97
	Prismatolaimus	1.54	1.83	0.93	1.84
	Rhabdolaimus	1.93	1.47	3.29	1.08
	Udonchus	0.19	0.18	0.56	0.26
	Tobrilus	2.31	2.20	3.54	2.27
	Tripyla	0.39	1.47	0.21	1.58
	Criconemoides	0.58	0.35	0.45	0.35
	Helicotylenchus	2.70	2.57	7.01	1.47
	Pratylenchus	0.58	0.55	0.19	0.26
	Trichodorus	0.77	0.73	0.95	0.41
	Achromadora	0.58	0.55	0.59	0.77
	Punctodora	0.19		0.14	
	Hirschmaniella	0.39	0.92	0.13	0.64
	Hoplolaimus	2.50	3.67	4.94	6.48
	Malenchus	0.77	0.92	0.21	1.19
	Merlinius	0.58	0.55	0.17	0.58
c-p 4	*Adenolaimus*	0.19	0.18	0.21	0.27
	Aporcedorus		1.47		0.69
	Dorylaimus	6.17	1.83	3.83	4.08
	Eudorylaimus	1.54	5.87	3.28	5.03
	Laimydorus	0.77	0.73	0.49	0.64
	Lordellonema	0.39	1.28	0.14	0.18
	Mesodorylaimus	2.12	2.02	1.56	2.05
	Moshajia	0.39	0.37	0.31	0.40
	Prodorylaimus	0.77	0.73	0.50	0.66
	Thornenema	0.77	1.65	0.42	1.74
	Discolaimium	0.58	0.55	0.24	0.79
	Discolaimus	0.58	0.92	0.56	0.73
	Ironus	0.39	0.37	0.35	0.46

Table II. (Continued).

c-p value	Nematode Genus	Relative occurrence		Relative abundance	
		KNP	YMP	KNP	YMP
	Labronema	1.54	1.47	1.02	1.34
	Mononchus	1.54	1.47	0.86	1.13
	Iotonchus		0.73		0.59
	Mylonchulus	0.77		0.45	
	Oriverutus	0.58	0.55	0.40	0.53
	Tylencholaimus		1.10		2.23
	Enchodelus		0.92		0.59
	Tyleptus		0.37		0.36
	Leptonchus		1.28		0.87
	Clarkus		1.10		0.62
c-p 5	*Belondira*	0.58	1.17	0.91	1.01
	Aporcelaimellus	0.39	1.02	0.24	0.79
	Aporcelaimus	0.19	3.51	0.21	0.75
	Aquatides	0.19	0.73	0.14	0.18
	Makatinus	0.39		0.25	
	Neoactinolaimus	0.19	0.73	0.14	0.18
	Nygolaimus	0.39	0.29	0.17	0.22
	Longidorus	0.77	1.46	0.39	0.27
	Xiphinema	1.54	2.93	0.35	0.46
	Axonchium		3.66		4.06
	Oxydirus		2.93		3.05
	Dorylaimellus		0.88		1.82
	Tylencholaimellus		1.02		2.40
	Discolaimoides		2.20		1.21
	Mylodiscus		0.29		0.50

quent and abundant than those with a lesser biomass (Fig. 3A_3, B_3).

KNP nematodes of the cp-4 guild had a greater biomass but lower density and frequency while YMP nematodes of the same guild had moderate to greater biomass but frequency and abundance ranged from low to moderate levels (Fig. 3A_4, B_4).

Nematodes of the highest guild cp-5 showed predominantly greater biomass but lower frequency and density. YMP showed dissimilar trends with the nematodes reflecting moderate values of biomass, density and frequency (Fig. 4A_5, B_5).

Diversity indices

The Shannon Wiener index of diversity (H') was estimated to be 3.55±0.63 and 4.05±0.44 for KNP and YMP respectively. Simpson's index of dominance (λ) for the two habitats was 0.95±0.24 and 0.98±0.31 re-

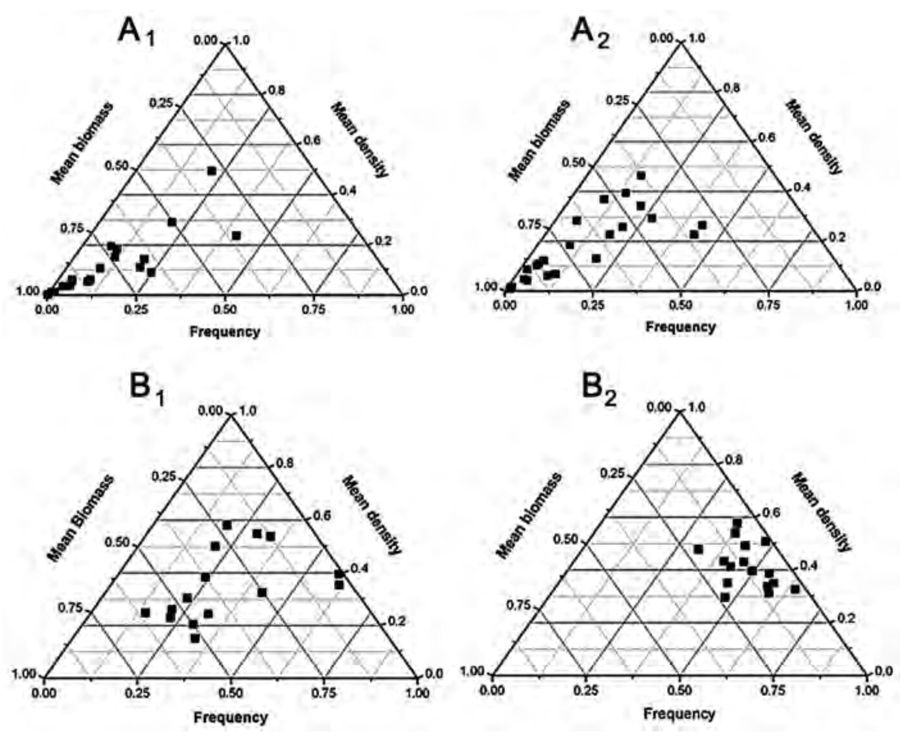

Fig. 2. Ternary showing relationship between biomass, frequency and density of *c-p* 1 (A_1-B_1) and *c-p* 2 (A_2-B_2) classes of KNP and YMP, respectively.

Table III. The nematode diversity and food web indices in the wetlands, Keoladeo National Park (KNP) and Yuan Ming Yuan Park (YMP).

Index	KNP	YMP
Simpson diversity index	0.95±0.24	0.98±0.31
Shannon Index	3.55±0.63	4.05±0.44
Margalef Index	11.05±0.60	11.58±0.12
Pielou J	0.78±0.38	0.93±0.43
Maturity Index	2.64±0.98	3.85±0.53
Plant Parasitic index	2.70±0.34	3.26±0.65
Nematode Channel ratio	0.89±0.14	0.64±0.10
Enrichment Index	60.98±8.23	75.87±3.08
Structure Index	76.13±3.04	91.34±2.38

spectively (Table III). The Margalef indices for KNP and YMP were 11.05±0.60 and 11.58±0.12, respectively, while the Pielou J' indices were 0.78±0.38 and 0.93±0.43, respectively (Table III).

The values of the Maturity Index (MI) ranged from 1.59 to 2.69 in KNP and from 3.01 to 3.98 in YMP. Plant Parasitic Index (PPI) values were estimated at 2.64-3.20 and 3.22-3.99 in KNP and YMP, respectively. The mean values are given in Table III.

Nematode Channel Ratio (NCR) for KNP and YMP was calculated to be 0.70-0.92 and 0.54-0.69, respectively. The Enrichment index varied from 48.01 to 66.75 and 72.54 to 79.09 in KNP and YMP, respectively, while Structure Index in the two habitats ranged from 71.81 to 80.32 (KNP) and 89.76 to 93.55 (YMP). The mean values are given in Table III.

DISCUSSION

Although extensive, the lists of genera presented for the two habitats may not be complete because sampling might preclude collecting all genera; some may occur in densities too low for detection or at a restricted time of the year or in specialized microhabitats. One such example is the absence of serious plant parasitic genera like *Heterodera* (cyst nematodes) and *Meloidogyne* (root knot nematodes). Their absence could be due to the fact that the nematodes were largely sampled from soils rather than roots of plants. Such unusual results were also reported by Talavera and Navas (2002), who could not find root knot nematodes in grassland samples. The results of Cadet and Floret (1995), Thioulouse *et al.* (1998) and Pate *et al.* (2000) further indicated that, over the years, the pathogenic species on plants were progressively replaced by many other, less pathogenic species.

The overall distribution pattern of nematodes was apparently correlated with the quantity and quality of food input and the substrate characteristics. The habitats under study showed a high diversity with fairly large numbers of nematode taxa; however, the composition of functional guilds was found to differ between the two habitats. The categorization based on *c-p* value and the food web indices also revealed specific clues about the habitat type as discussed below.

Keoladeo National Park

As a general trend, the individuals of cp 1-5 classes in KNP exhibited greater biomass but less frequency and

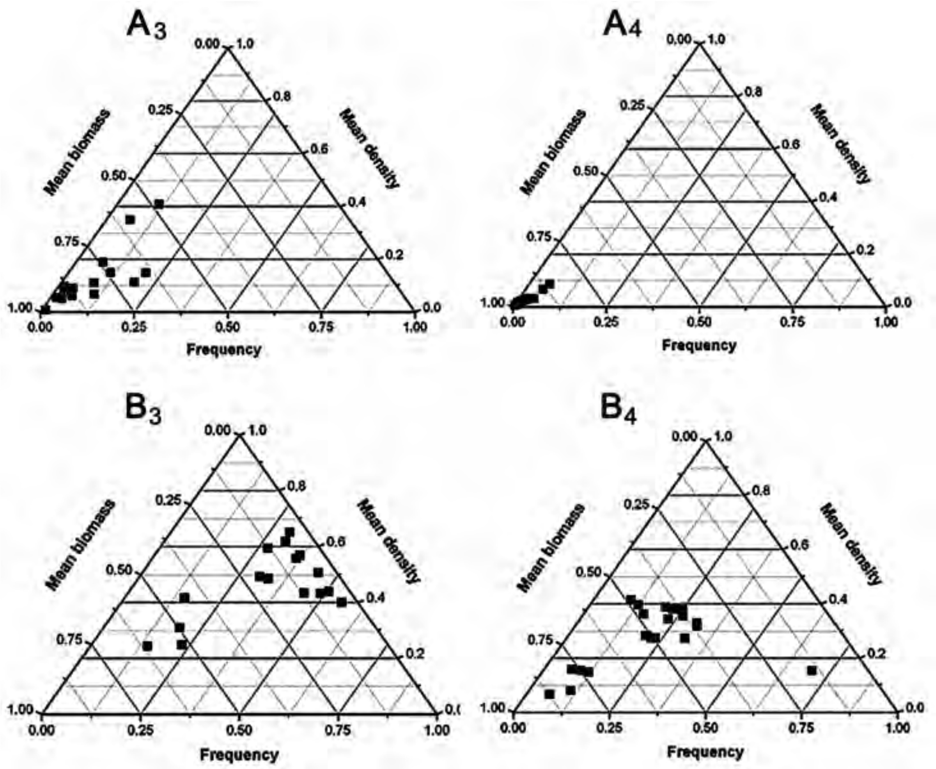

Fig. 3. Ternary showing relationship between biomass, frequency and density of *c-p* 3 (A_3-B_3) and *c-p* 4 (A_4-B_4) classes of KNP and YMP, respectively.

density. Among the *c-p* classes, the greatest generic diversity was exhibited by *c-p* 2. The basal guild also predominated with respect to the density of individuals. *Cephalobus* was the most prevalent and abundant genus in the collected samples. Referred to as general opportunists (Bongers *et* Ferris, 1999), such cephalobs are considered to be adapted to stress conditions and are capable of prolonged cryptobiotic survival with undetectable metabolic activity (Ferris *et al.*, 2001). The KNP receives no external input in the form of organic amendments and the rainfall is low and sporadic. Hence, conditions of less enrichment or stress could occur as is also reflected by low EI at various sampling stations. However, the organic matter sufficed and mainly supported the bacterivores (Ba) as the arid and less humid conditions prevented the bloom of fungi or fungal feeders (Fu) (NCR = 0.89±0.14). Despite the predominance of basal indicators, a fair percentage of Ba_3, Fu_3, Ca_3 and Om_3 taxa as well as Ba_4, Fu_4, Ca_4 and Om_4 taxa ensured a structured status to the substrata of KNP, as also depicted by the indicator values of EI and SI (Fig. 4A'). Mean Maturity Index (2.64±0.98) of KNP reflected relatively stable environmental conditions; nevertheless, the low values (in the range 1.59-2.69) of MI in a few samples reflected the incidence of disturbances. The relatively greater prevalence and abundance of *Tobrilus* in this context seems reasonable since it has often been reported from oxygen stressed substrata (Nuss, 1984; Jacobs 1987; Beier *et* Traunspurger, 2003a, b). A fair percentage of the bacterivore *Rhabdolaimus* from aquatic sites, stated to survive as a dauer stage in warm dry and acidic soils (Dmowska, 2000; Beier *et* Traunspurger, 2001), may be indicative of the frequent drying and wetting properties of the substrate in KNP. Mean Plant Parasitic Index (2.70±0.34) indicated the dominance of ectoparasites with *c-p* value 3 or higher; these seem to be tolerated by the plants of the wetland and may even have led to compensatory plant growth.

Yuan Ming Yuan Park

In YMP, the greatest generic diversity represented by the *c-p* 4 class reflected its dominance in the park food web. The structured status of YMP was further confirmed by the dominance of structure guilds 3-5, which constituted 75% of individuals. The most frequent genus *Aphelenchus* and the most abundant genus *Hoplolaimus* also indicated the relative low impact of primary enrichment guild (Ba_1, Fa_1). YMP samples were generally comprised of the nematodes with moderate biomasses, frequencies and densities as reflected by the ternary of different *c-p* classes. The dominance of the k-strategists indicated a relatively balanced and stable environment. The YMP is a maintained garden, thus the substrata receive organic input as amendments and this is reflected by a high EI (Fig. 4B'). The moisture is adequate enough to promote fungal growth and bacterial bloom. However, the bacterial decomposition pathway (NCR = 0.64±0.10) seemed to supersede the fungal decomposition pathway. An abundance of Ba_4, Fu_4, Ca_4 and Om_4 taxa ensured a structured status to the substrata of YMP as also depicted by the indicator values of SI (Fig. 4B'). Mean Maturity In-

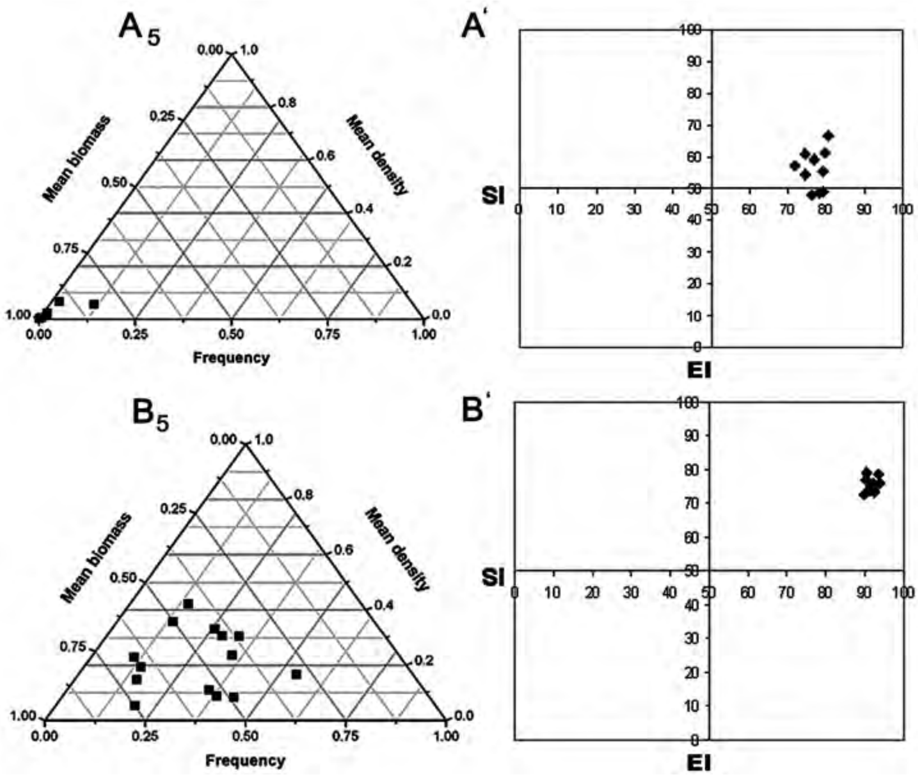

Fig. 4. Ternary showing relationship between biomass, frequency and density of *c-p* 5 (A_5-B_5) and the indicator values of EI (Enrichment Index) and SI (Structure Index) in KNP and YMP, respectively (A'-B').

dex (3.85±0.53) of YMP reflected a highly stable and structured ecosystem free from perturbations. Mean Plant Parasitic Index (3.26±0.65) indicated the high incidence of plant parasites, which were largely ectoparasites associated with ornamentals. The presence of sensitive Longidoridae indicated stability of environment. Furthermore, the abundance of the nematodes with overlapping pharyngeal glands *viz.*, *Helicotylenchus* and *Hoplolaimus* also reflected a stable habitat as reported by Bongers (1990).

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