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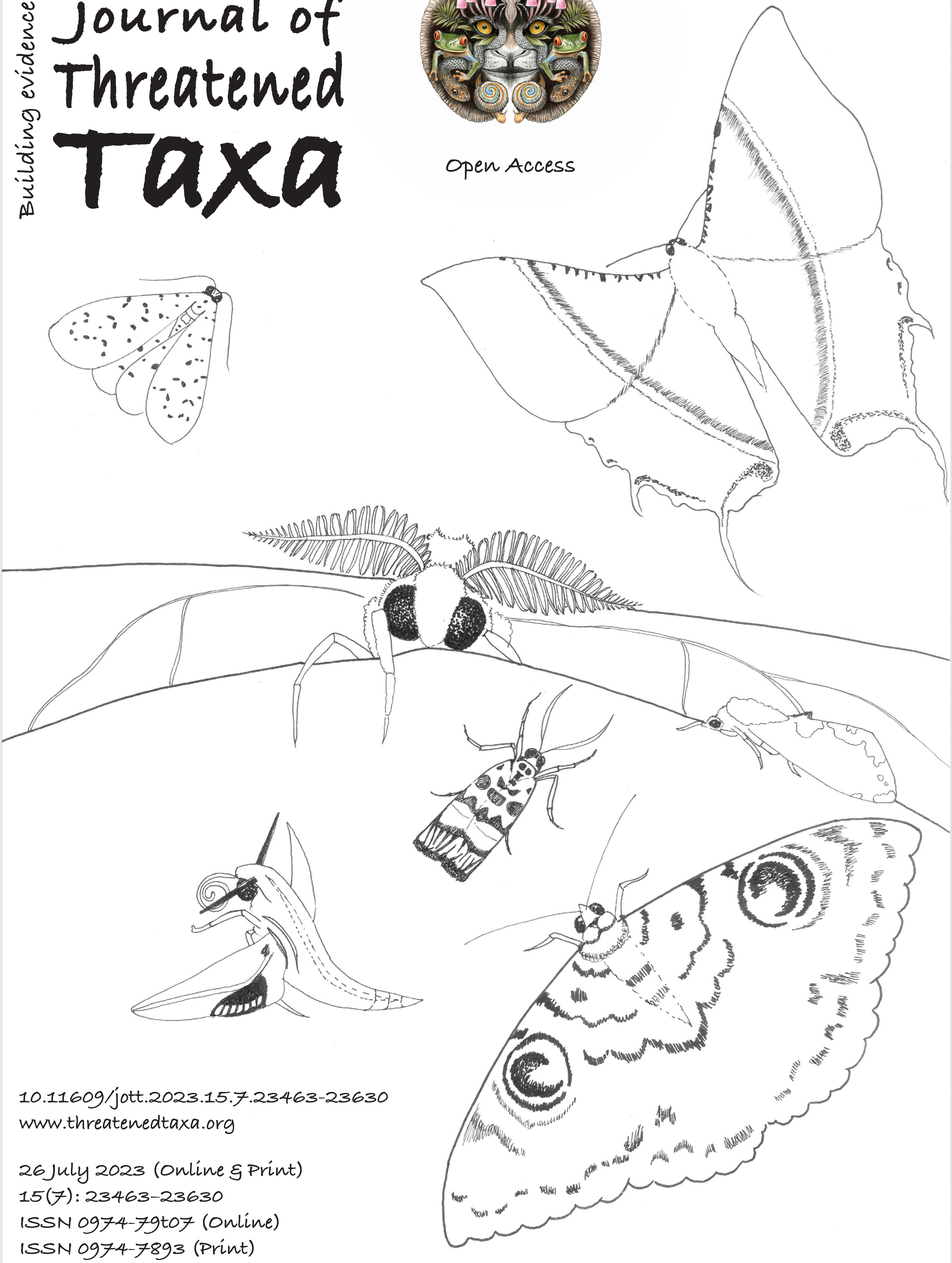

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Cover: Celebrating the unsung heroes—moths, our nocturnal pollinators. © Priyanka Iyer.

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COMMUNICATION

Checklist of soil nematode diversity from Udupi District, Karnataka, India

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Abstract: Nematodes are plentiful in soil and may be found in practically every habitat. Around 25% of global biodiversity is considered to be supported by terrestrial ecosystem soils. There has been less research on nematode populations in Karnataka than there has been in other states. The scarcity of available literature provides up even more opportunities for studying these faunas in this region. As a result, the following investigation was conducted. The major goal of this research was to investigate the nematode diversity in the Udupi area. The collected nematodes were fixed, dehydrated, and displayed on a glass slide after isolation. Published keys were used to identify the species; there were 2,833 individual nematodes recovered. This collection contained 49 soil nematode species, which were classified into 34 genera and 20 families distributed over seven orders.

Keywords: Bacterial feeders, c-p values, fungal feeders, Mononchida, NEMAPLEX, Tylenchida.

Kannada: ದುಂಡುಹುಳಗಳು ಮಣ್ಣಿನಲ್ಲಿ ಹೇರಳವಾಗಿವೆ ಹಾಗೂ ಪ್ರತಿಯೊಂದು ಆವಾಸಸ್ಥಾನದಲ್ಲಿ ಅವುಗಳು ಕಂಡುಬರಬಹುದು. ಜಾಗತಿಕ ಜೀವವೈವಿಧ್ಯದ ಶೇಕಡಾ 25ರಷ್ಟು ಮಣ್ಣಿನಲ್ಲಿ ಜೀವಿಸುತ್ತವೆಂದು ಅಂದಾಜಿಸಲಾಗಿದೆ. ಕರ್ನಾಟಕದಲ್ಲಿ ದುಂಡುಹುಳಗಳು ಬಗ್ಗೆ ತೀರಾ ಕಡಿಮೆ ಸಂಶೋಧನೆ ನಡೆದಿರುವುದು, ಲಭ್ಯ ವೈಜ್ಞಾನಿಕ ದಾಖಲೆಗಳಿಂದ ಧೃಡಪಡುತ್ತದೆ. ಸಾಹಿತ್ಯದ ಲಭ್ಯತೆಯ ಕೊರತೆಯು ಈ ಪ್ರದೇಶದಲ್ಲಿ ಈ ಪ್ರಾಣಿಗಳನ್ನು ಅಧ್ಯಯನ ಮಾಡಲು ಇನ್ನಷ್ಟು ಅವಕಾಶಗಳನ್ನು ಒದಗಿಸುತ್ತದೆ. ಇದರ ಪರಿಣಾಮವಾಗಿ, ಈ ಸಂಶೋಧನೆಯನ್ನು ನಡೆಸಲಾಯಿತು. ಉಡುಪಿ ಪ್ರದೇಶದಲ್ಲಿ ಲಭ್ಯವಿರುವ ಮಣ್ಣಿನ ದುಂಡುಹುಳಗಳು ವೈವಿಧ್ಯತೆಯನ್ನು ಅಧ್ಯಯನ ಮಾಡುವುದು ಈ ಸಂಶೋಧನೆಯ ಪ್ರಮುಖ ಗುರಿಯಾಗಿದೆ. ಉಡುಪಿಯ ಬೇರೆ ಬೇರೆ ಭಾಗಗಳಿಂದ ಸಂಗ್ರಹಿಸಿದ ಮಣ್ಣಿನಿಂದ ದುಂಡುಹುಳಗಳನ್ನು ಬೇರ್ಪಡಿಸಿ ಅದನ್ನು ನಿರ್ಜಲೀಕರಿಸಿ ಗ್ಲಾಸ್ ಸ್ಲೈಡ್‌ನ ಮೇಲೆ ಅಂಟಿಸಿ ಆನಂತರ ಅವುಗಳ ಚಿತ್ರ ಹಾಗೂ ರೇಖಾಚಿತ್ರಗಳನ್ನು ತೆಗೆದುಕೊಳ್ಳಲಾಯಿತು. ನಂತರ ಈಗಾಗಲೇ ಲಭ್ಯವಿರುವ ಸಾಹಿತ್ಯವನ್ನು ಆಧರಿಸಿ ಅವುಗಳನ್ನು ಗುರುತಿಸಲಾಯಿತು. ಒಟ್ಟು 2833 ದುಂಡುಹುಳಗಳನ್ನು ಈ ರೂಪದಲ್ಲಿ ಸಂಗ್ರಹಿಸಿ ಅವುಗಳಲ್ಲಿ ಒಟ್ಟು 20 ಕುಟುಂಬಕ್ಕೆ ಸೇರಿದ 34 ತಳಿಯ 49 ಜಾತಿಯ ಮಣ್ಣಿನ ದುಂಡುಹುಳಗಳನ್ನು ಗುರುತಿಸಿ ಇಲ್ಲಿ ವರದಿ ಮಾಡಲಾಗಿದೆ.

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Author contributions: KM designed the study, conducted field work, data collection, data analysis and wrote the manuscript. SA supervised the research, designed the study, contributed in data analysis, and provided multiple revisions in the early stages of writing. Both authors read and approved the final manuscript.

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INTRODUCTION

Nematodes are ubiquitous in soil and occur in almost every type of ecosystem (Coleman et al. 2004). In terms of diversity and abundance, nematodes are one of the most diverse and abundant phyla in the animal kingdom. They have a high degree of genetic diversity and phenotypic plasticity, allowing them to colonize a wide variety of habitats. Nematodes are the most numerous multicellular animals that live in the soil, and feed and reproduce in the water film surrounding and within soil aggregates. Nematodes, which are comprised of over 30,000 described species, exist in almost all possible environment on the planet and account for more than 80% of metazoan taxonomic and functional diversity in soil (Nisa et al. 2021).

Terrestrial ecosystem soils are thought to sustain around 25% of global biodiversity. Although there are more than a million nematode species predicted, only about 30,000 have been discovered (Kiontke & Fitch 2013; Nisa et al. 2021). The greatest nematode abundance (309,000 individuals per kilogram of dry soil) was found around latitude 50^0, with an average of 27,600 individuals per kg of dry soil (Song et al. 2017). Nematodes are an essential component of the soil microbiota, aiding in the regulation of a wide range of ecosystem functions including mineral cycling, succession processes, and energy flow (Nisa et al. 2021).

In Karnataka, there have been comparatively fewer studies on nematode communities. The insufficiency of existing literature opens even greater possibilities for exploring these fauna in this area. Ravichandra & Krishnappa (2004) and Kantharaju et al. (2005) have studied the prevalence, distribution, pathogenicity, and control of economically important plant parasitic nematodes. It is reasonable to assume that investigations on nematodes other than commercially important species have not been conducted in the study region. As a consequence, the following investigation has been carried out. The primary purpose of this study was to explore the nematode diversity in the Udupi region.

MATERIALS AND METHODS

Study Area

Udupi is wedged between the Western Ghats on the east and the Arabian Sea on the west (Figure 1). Udupi district has an area of 3,880 km^2 and is situated at 13.33^{0}N & 74.74^{0}E at an average elevation of 27 m. The area of Udupi adjacent to the sea is plain with tiny hills, rice fields, coconut groves, and urban areas. Summers (March–May) can reach 38^{0}C, while winters (December–February) range 32–20 ^{0}C. The monsoon season lasts from June to September, with annual rainfall averaging over 4,000 mm (160 in) and strong winds (District Disaster Management Authority 2022).

Collection of soil samples

From each of Udupi's seven taluks, 25 soil and 25 sediment samples were collected. Soil cores were sampled using opportunistic sampling (Williams & Brown 2019). A soil auger or hand spade was used to collect soil and sediments. Sampling was done at a depth of 10 to 15 cm in the early hours of the day. Five to six cores of soil around the plant roots were excavated, and roughly 1 kg of soil was collected and put into zip lock polythene bags, which were then immediately moved to a chiller with a temperature of 4^{0}C, and carried until further processing (Ravichandra 2014).

Isolation of nematodes from soil

Nematodes were isolated employing Cobb's sieving and decanting technique. The murky filtrate was then subjected to Bearman's Funnel technique for isolation (Sikora et al. 2018).

Killing, processing, and fixing the nematodes

The nematode suspension thus obtained was placed in a test tube for 20–30 minutes to allow the nematodes to settle to the bottom. The bulk of the water was gently emptied from the test tube using a dropper and killed suddenly by plunging it in hot 4% formalin (heated to 60° C). Killed nematodes were fixed in 5 parts of glycerine and 95 parts of alcohol fixative and allowed for slow dehydration in a desiccator with calcium chloride as a desiccant for about three weeks (Ravichandra 2014).

The fixed nematodes were then carefully extracted, and permanent slides were made by employing the wax ring technique with a drop of pure anhydrous glycerine. Toup-view micrometry software was used to make measurements, and de man's indices (de Man 1884) were used to make measurements (Sikora et al. 2018). Species were identified following keys available in Siddiqui (2000), Ahmad & Jairajpuri (2010), Bohra (2011), and the NEMAPLEX website (Nemaplex 2022). Each individual was assigned to respective trophic group according to Yeates et al. (1993) and various feeding habits according to Bongers & Bongers (1998).

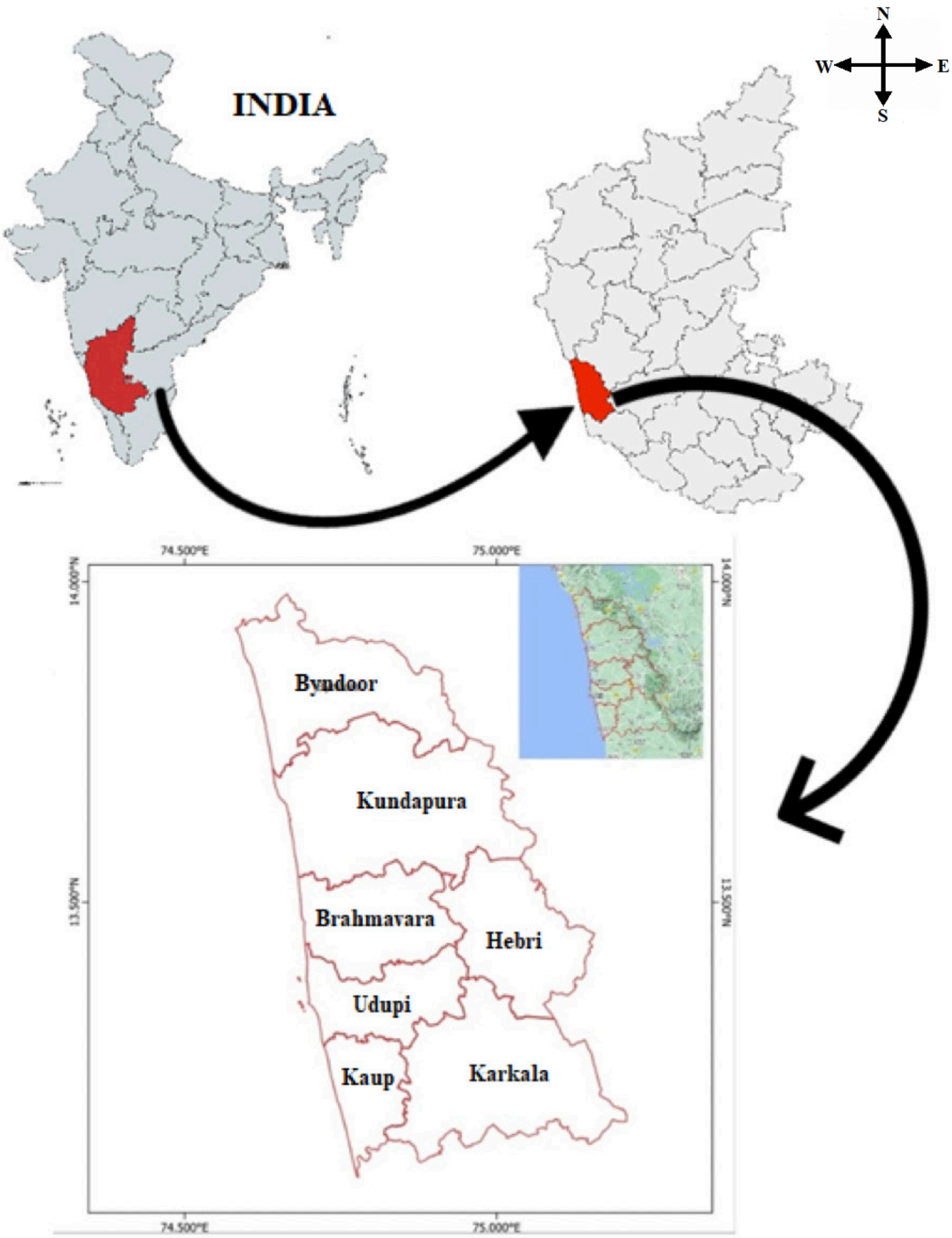

Figure 1. Map of the study area.

RESULTS

The total number of individual nematodes isolated from the soils collected from the research area was 2833. This comprised of 49 species of soil nematodes belonging to 34 genera and 20 families distributed among seven orders. Order Tylenchida was the most dominant order represented by 27 species (57%) followed by the Dorylaimida with 11 species (23%), Aphelenchida with four species (8%), Mononchida with three species (6%), Rhabditida with two (4%), Araeolaimida (2%), and Monhysterida (2%) were represented by a species each (Figure 2). Family Qudsianematidae and Tylenchidae were the families comprising the highest number of species (Figure 3). The detailed family-wise species representation is displayed in Table 1. Photographs of few selected nematodes are given in Image 1–34.

Yeats et al. (1993) identified eight distinct types of nematode feeding. The feeding categories have also been attributed to the species inventory of the present study. The species that belong to feeding type 1 (plant feeders) are the most prevalent community, with 24 species representing the category, nine species belong to feeding group 5 (predators), six to feeding type 8

Table 1. Names of documented species (with feeding type) and their family. (With C-p values and feeding habit). All names are after Bohra (2011)

	Name of the species (under various families)	C-p Value	Feeding habit
	Family 1: Anguinidae		
1.	*Ditylenchus clarus* Thorne and Malek, 1968	2	Fungal-feeding
	Family 2: Aphelenchoididae		
2.	*Aphelenchoides asterocaudatus* Das, 1960	2	Plant-feeding
3.	*Aphelenchoides longiurus* Das, 1960	2	Plant-feeding
4.	*Aphelenchoides besseyi* Christie, 1942	2	Plant-feeding
5.	*Aphelenchoides bicaudatus* (Imamura, 1931) Filipjev and Stekh., 1941)	2	Plant-feeding
	Family 3: Cephalobidae		
6.	*Zeldia puntata* (Thorne, 1925) Thorne, 1937	2	Bacterial-feeding
7.	*Cephalobus bodenheimeri* (Stainer, 1936) Andrassy, 1984	2	Bacterial-feeding
	Family 4: Dorylaimidae		
8.	*Mesodorylaimus mesonyctius*	4	Omnivore
9.	*Dorylaimis stagnalis* Dujardin, 1835	4	Omnivore
10.	*Mesodorylaimus margeritus* Basson and Heyns, 1974	4	Omnivore
11.	*Laimydorus serpentines* (Thorne and Swanger, 1936) Siddiqi, 1969	4	Omnivore
	Family 5: Hoplolaimidae		
12.	*Helicotylenchus martini* Sher, 1960	3	Plant-feeding
13.	*Hlelicotylenchus indicus* Siddiqi and Husain, 1964	3	Plant-feeding
14.	*Helicotylenchus digitatus* Siddiqi and Husain, 1964	3	Plant-feeding
	Family 6: Iotonchidae		
15.	*Iotonchus trichuris* (Cobb, 1917) Mulvey, 1963	4	Predators
	Family 7: Longidoridae		
16.	*Longidorus proximus* Sturhan and Agro, 1983	5	Plant-feeding
17.	*Longidours minrus* Khan et al., 1972	5	Plant-feeding
18.	*Longidorus elongatus* (de Man, 1876) Micoletzky, 1922	5	Plant-feeding
19.	*Paralongidorus sp*	5	Plant-feeding
	Family 8: Meloidogynidae		
20.	*Meloidogyne javanica* (Treub, 1885) Chitwood, 1949	5	Plant-feeding
21.	*Meloidogyne incognita* (Kofoid and White, 1919) Chitwood, 1949	3	Plant-feeding
22.	*Heterodera cajani* Koshi, 1967	3	Plant-feeding
23.	*Heterodera zeae* Koshy, Swarup and Sethi, 1971	3	Plant-feeding
	Family 9: Monhysteridae		
24.	*Monhystera* spp.	2	Bacterial-feeding
	Family 10: Mononchidae		
25.	*Mononchus* spp.	4	Specialist Predators
	Family 11: Mylonchulidae		
26.	*Mylonchulus minor* (Cobb, 1893) Andrassy, 1958	4	Specialist Predators
	Family 12: Nordiidae		
27.	*Kochinema sectum* Siddiqi, 1966	4	Generalist predators
	Family 13: Nygolaimidae		
28.	*Nygolaimus anneckei* Heyns, 1969	5	Generalist predators
	Family 14: Paratylenchidae		
29.	*Paratylenchus curvitatus* Van der Linde, 1938	2	Plant-feeding
30.	*Paratylenchus nainianus* Edward and Misra, 1963	2	Plant-feeding
	Family 15: Plectidae		
31.	*Plectus parvus* Bastian, 1865	2	Bacterial-feeding
	Family 16: Pratylenchidae		
32.	*Pratylenchus coffeae* (Zimmerman, 1898) Filipjev and Stekhoven, 1941	3	Plant-feeding
33.	*Pratylenchus thornei* Sher and Allen, 1953	3	Plant-feeding
	Family 17: Qudsianematidae		
34.	*Eudorylaimus centrocercus* (De Man, 1880) Andrassy, 1959	4	Generalist predators
35.	*Eudorylaimus longicardiu*, Thorne, 1974	4	Generalist predators
36.	*Discolaimus rotundicaudatus*, Khan and Laha, 1982	4	Generalist predators
37.	*Moshajia cultristyla* Siddiqi, 1982	4	Generalist predators
38.	*Discolaimus agricolus* Sauer and Annells, 1986	4	Generalist predators
39.	*Discolaimus major* Thorne, 1939	4	Generalist predators
	Family 18: Telotylenchidae		
40.	*Tylenchorhynchus zeae* Sethi and Swarup, 1968	3	Plant-feeding
41.	*Tylenchorhynchus clarus* Allen, 1955	3	Plant-feeding
42.	*Qunisulcius capitatus*	3	Plant-feeding
	Family 19: Tylenchidae		
43.	*Tylenchus magnus* Khurana and Gupta, 1988	2	Plant-feeding
44.	*Aglenchus agricola (de Man, 1884) Meyl, 1961*	2	Plant-feeding
45.	*Filenchus filifornis* (Brzeski, 1963) Lownsbery and Lownsbery, 1985	2	Plant-feeding
46.	*Sakia alii* Suryawanshi, 1971	2	Plant-feeding
47.	*Boleodorus brevistylus* Khera, 1970	2	Plant-feeding
48.	*Basiria graminophila* Siddiqi, 1959	2	Plant-feeding
	Family 20: Xiphinematidae		
49.	*Xiphinema americanum* Cobb, 1913	5	Plant-feeding

1–5—colonizers – persisters | c-p-value—structural guild: 1—enrichment opportunists | 2—basal fauna | 3—early successional opportunists | 4—intermediate succession and disturbance sensitivity | 5—long-lived intolerant species. Allotments follow Bongers & Bongers (1998).

(omnivores), six to feeding type 2 (hyphal feeding) and four to feeding type 3, which includes bacterial feeders. A further inspection of the pooled data reveals that plant-feeding taxa form a significant trophic community in this region, with omnivore and fungal feeders having relatively little representation. Herbivore nematode fauna is relatively higher when compared to the other groups probably due to the restriction of sampling sites to the areas with lush vegetation. Allocation of documented taxa to various trophic guilds following Yeats et al. (1993) indicated that throughout the documented nematode families, there are nine plant-feeding, six predatory, three bacterial feeders, one omnivore, and a fungal-feeding nematode family.

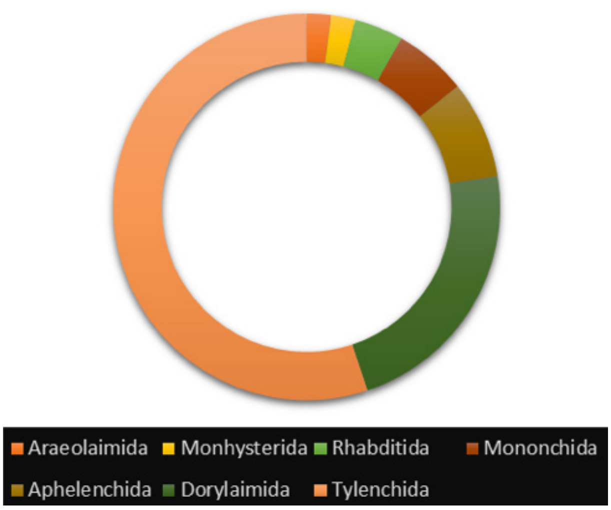

Figure 2. Percent representation of different nematode orders.

C-p values (Colonizer-Persister) were allocated to each documented family following Bongers & Bongers (1998) (Table 3). Soil nematodes were classified into one of five colonizer-persister groups which range between extreme r- to extreme k-strategists. "Colonizer" nematodes at the lower end of the scale of the c-p scale are thought to be enrichment opportunists and so suggest resource availability; "persister" nematodes at the high end of the scale imply system stability, food web complexity, and connectance. C-p value range from 1 to 5 where the classification is mainly based on lifespan (Increasers with the scale), gonad to body volume (Increasers with the scale), sensitivity to soil perturbances which also increases with the scale and hence indicate the health of the soil.

DISCUSSION

This is a preliminary (possibly the first) study that focuses on the overall diversity of soil nematode communities in the Udupi region. We want to continue

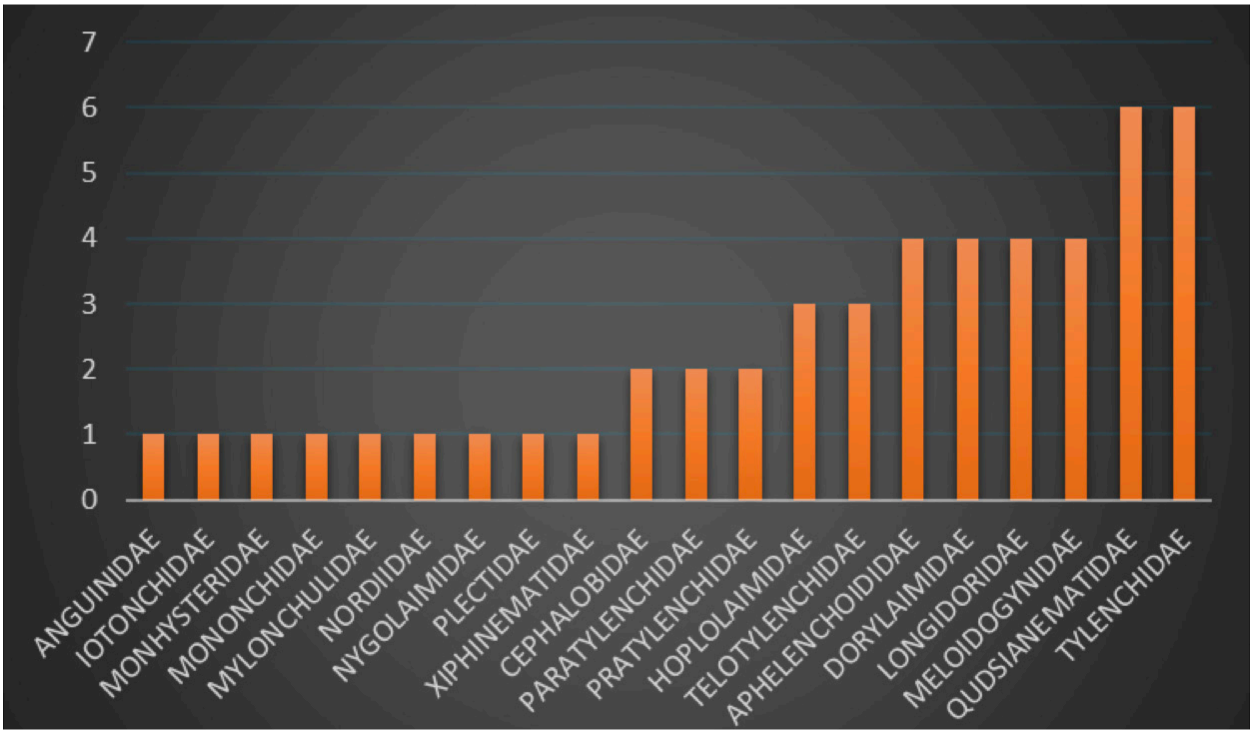

Figure 3. Number of species representing different nematode families.

Image 1–9. 1—*Ditylenchus clarus* | 2—*Aphelenchoides asterocaudatus* | 3—*Aphelenchoides longiurus* | 4—*Aphelenchoides besseyi* | 5—*Dorylaimis stagnalis* | 6—*Laimydorus serpentine* | 7—*Helicotylenchus martini* | 8—*Helicotylenchus digitatus* | 9—*Iotonchus trichuris*. Scale: 1,2,3 & 9—10 µm | 4–8—100 µm. © Keshava Murthy M V.

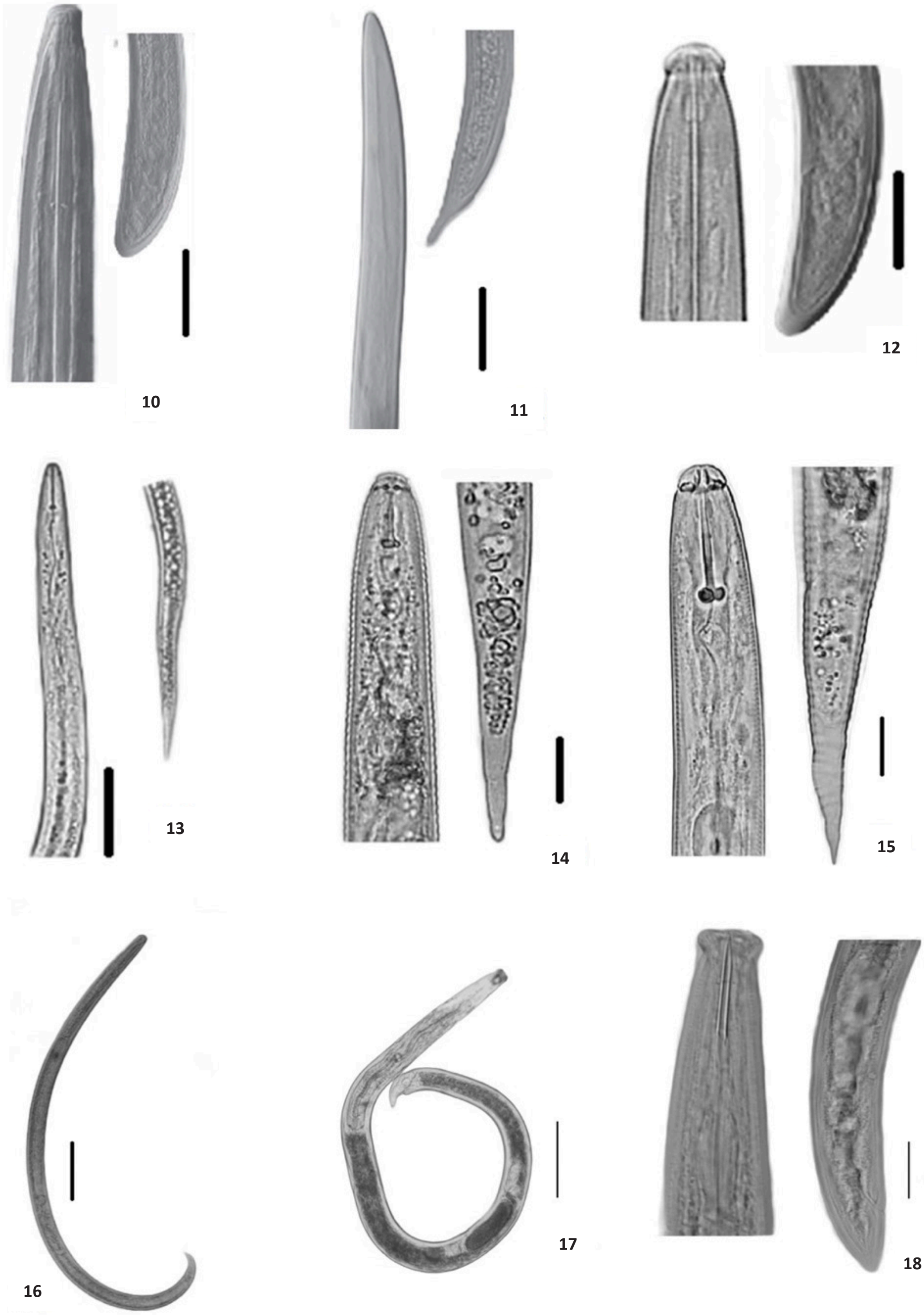

Image 10–18. 10—*Longidorus proximus* | 11—*Longidours minrus* | 12—*Paralongidorus* sp. | 13—*Meloidogyne javanica* | 14—*Meloidogyne incognita* | 15—*Heterodera zeae* |16—*Mononchus* sp. | 17—*Mylonchulus minor* | 18—*Kochinema sectum*. Scale: 10–15 & 18—10 µm | 16–17—100 µm. © Keshava Murthy M V.

Image 19–27. 19—*Paratylenchus curvitatus* | 20—*Paratylenchus nainianus* | 21—*Plectus parvus* | 22—*Pratylenchus coffeae* | 23—*Pratylenchus thornei* | 24—*Eudorylaimus centrocercus* | 25—*Eudorylaimus longicardius* | 26—*Discolaimus agricolus* | 27—*Tylenchorhynchus clarus*. Scale: 19–24 & 26–27—10 µm | 25—100 µm. © Keshava Murthy M V.

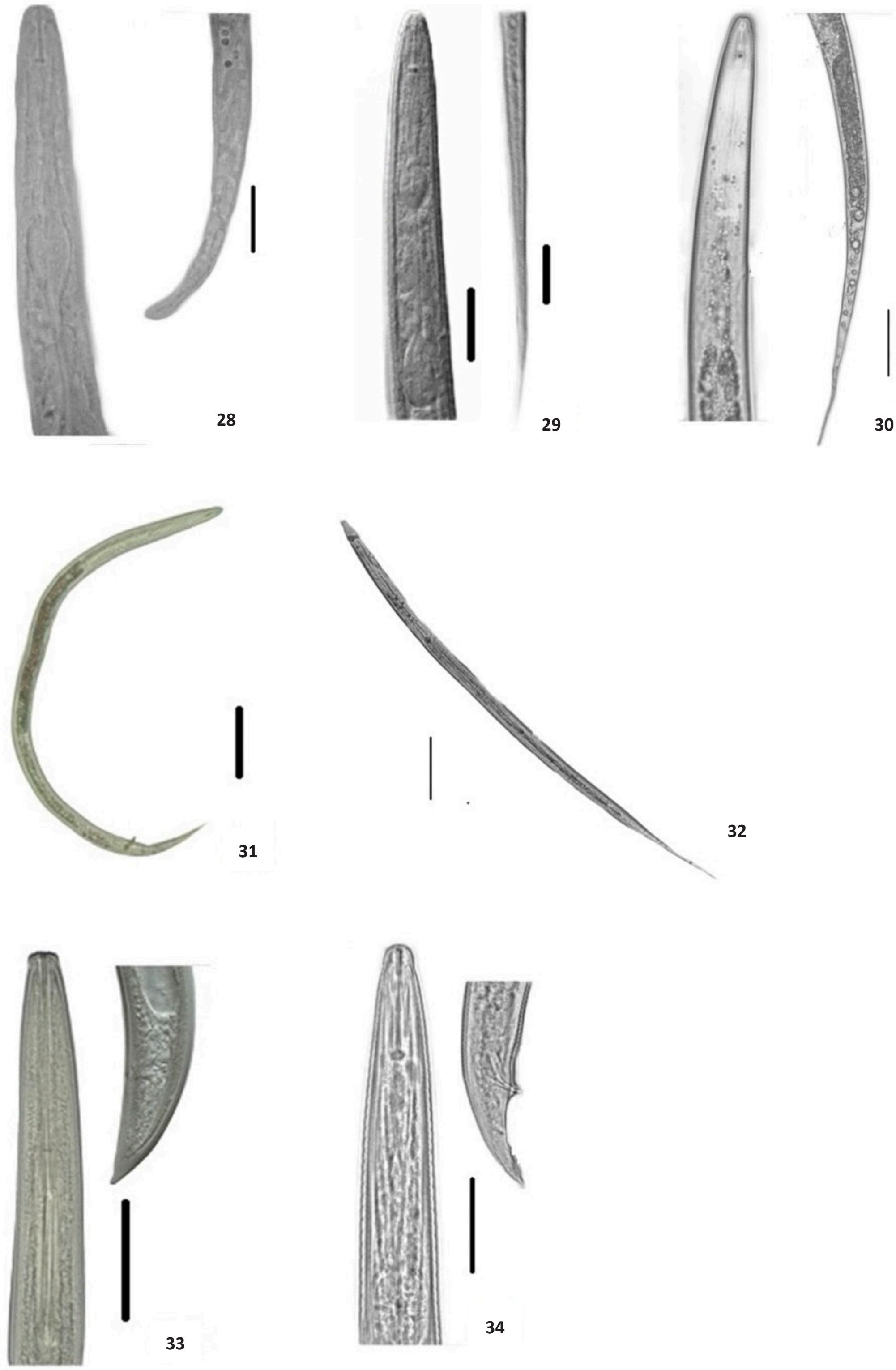

Image 28–34. 28—*Tylenchus magnus* | 29—*Aglenchus agricola* | 30—*Filenchus filifornis* | 31—*Boleodorus brevistylus* | 32—*Basiria graminophila* | 33—*Xiphinema amerincanum* | 34—*Tylenchorhynchus zeae*. Scale: 28–30 & 33–34—10 µm | 31—50 µm | 32—75 µm. © Keshava Murthy M V.

the research, taking into account many soil parameters that influence nematode bioecology, to uncover the likely drivers of nematode assemblages in the soil of Udupi district. Nematodes are good models of soil health indicators since they are widespread and distributed over a variety of feeding behaviors and trophic guilds (Kergunteuil et al. 2016). It's astounding that microbial biogeography still lacks a map, given that the great majority of biodiversity is found in microscopic taxa rather than macroscopic taxa. Also, considering that microscopic species play critical roles in ecosystem functioning via decomposition and nutrient mineralization processes, it is surprising that we still don't know much about patterns of nematode diversity and nematode assemblages in soil ecosystems (Porazinska et al. 2012). More comprehensive studies on nematode populations in Udupi might yield exciting results that help us to monitor soil quality and, if required, to design and implement mitigation strategies.

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